Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings

Volume I: Energy Consumption Baseline

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1 Acknowledgements

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2 Executive Summary

ADL carried out a "bottom-up" study to quantify the annual electricity consumption (AEC) of more than thirty (30) types of non-residential[1] office and telecommunications equipment. The Office of Building Technology, State and Community Programs at the U.S. Department of Energy commissioned the study to develop technically-detailed and carefully laid out AEC estimates for the major equipment types to assist in the planning of future research and development, deployment and standards programs. Prior studies did not completely fulfill the Department's needs for energy consumption data and identification of key trends.

A preliminary AEC estimate for all equipment types identified eight key equipment categories that received significantly more detailed studied (see Table 2-1) and accounted for almost 90% of the total preliminary AEC.

Table 2-1: Key Equipment Categories

Key Equipment Categories
Computer Monitors and Displays
Personal Computers
Server Computers
Copy Machines
Computer Network Equipment
Telephone Network Equipment
Printers
Uninterruptable Power Supplies (UPSs)

The literature review did not uncover any prior comprehensive studies of telephone network electricity consumption or uninterruptable power supply (UPS) electricity consumption. Thus, this study is the first to address the energy consumption of both telephone networks and UPSs.

Office and Telecommunication Equipment Electricity Consumption in Y2000

The AEC analyses found that the office and telecommunications equipment consumed 97-TW-h of electricity in Y2000, and that the key equipment categories accounted for almost 90% of the total (see Figure 2-1).

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[1] Includes equipment in commercial and industrial buildings, as well as telecommunications equipment not in buildings (e.g., on pedestals, cell towers, etc.).

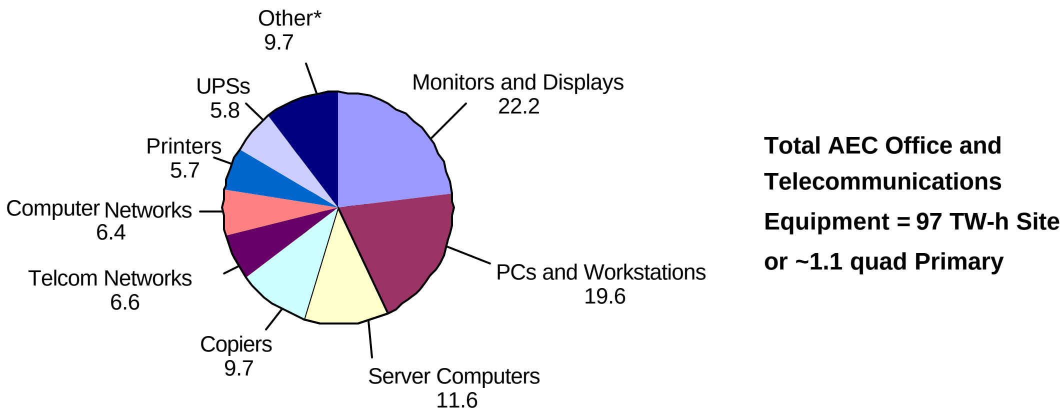

Figure 2-1: Non-Residential Office and Telecommunications Equipment Annual Energy Consumption for Y2000, in quadrillion primary Btu (quads)

Personal computers and their monitors represented almost 40% of the total AEC (~42TW-h site, or ~0.46 quads). The equipment forming the backbone of the Internet (server computers, computer networks, telephone networks, and UPSs) consumed around 30% of all non-residential office and telecommunications equipment electricity (~30TW-h site, or ~0.33 quads primary). In the context of the ~133 million PCs installed (both residential and non-residential) in the U.S. in Y2000, this equates to an average continuous[2] power draw of just over 25W per PC. Imaging devices (copiers and printers) accounted for more than 15% of electricity consumed (~15TW-h site, or ~0.17 quads).

Non-residential office and telecommunications equipment accounted for 3% of national electricity consumption in Y2000 (see Table 2-2) or, put in another context, about 9% of electricity consumed nationwide in commercial buildings. Similarly, non-residential office and telecommunications equipment consumed ~1.1% of the 97.7 quads of primary energy consumed in the U.S. in Y2000.

[2] Over 8,760 hours in a year.

* "Other" includes: Facsimile machines, desktop and handheld calculators, point-of-sale (POS) terminals, electric typewriters, automated teller machines (ATMs), scanners, very small aperture terminals (VSATs), scanners, supercomputers, voice mail systems (VMSs), smart handheld devices, and dictation equipment.

Table 2-2: Comparison of Non-Residential Office and Telecommunications Equipment Electricity and Energy Consumption to Commercial Building Sector and National Electricity and Energy Consumption in Y2000

Sector	Electricity Consumed (TW-h)	Primary Energy Consumed (Quads)	Source
Non-Residential Office and Telecommunications Equipment	97	1.07 [3]	Current Report
Commercial Sector	1,100	16.0	BTS (2001)
National Total	3,610	97.7	EIA (2001c)

Scenario-Based Projections of Office and Telecommunication Equipment Electricity Consumption in Y2005 and Y2010

The investigation also developed three distinct scenarios to develop projections of the possible range of future office and telecommunications equipment electricity consumption for the key equipment types in Y2005 and Y2010 (see Table 2-3 for scenario descriptions).

Table 2-3:Scenario Descriptions

Scenario	Key Features
Ubiquitous Computing	• Continuous connectivity becomes a way of life, via computers and smart handheld devices wireless phones with advanced functionality • Internet access quality (bandwidth) and reliability paramount
PC Reigns	• Computing remains firmly anchored to the desktop PC – most workers have a PC • PC performance highly valued • Widespread high-bandwidth connectivity to enable effective exchange of large quantities of data and programs run efficiently by local PCs (e.g., video)
Greening of IT	• European Community and Japanese sign the Kyoto Accord • Energy consumption of office and telecommunication equipment becomes a major concern • Power-aware design becomes the rule for office and telecommunications equipment hardware and consumables

[3] Based upon a primary-to-electricity conversion ratio of 10,958 Btu per kW-h (BTS, 2001).

* "Other" includes: Facsimile machines, desktop and handheld calculators, point-of-sale (POS) terminals, electric typewriters, automated teller machines (ATMs), scanners, very small aperture terminals (VSATs), scanners, voice mail systems (VMSs), smart handheld devices, and dictation equipment.

The AEC of the scenario that predicts the largest growth in office and telecommunications equipment AEC, PC Reigns, consumes ~3.5% of the projected national electricity consumption in Y2010[4] (see Figure 2-2); this equals ~12% of projected commercial building electricity consumption for Y2010 (BTS, 2001). At the other bound, in the Greening of IT scenario, office and telecommunications equipment AEC decreases by approximately 25% to account for less than 2% of national electricity consumption, or about 6% of projected commercial building electricity consumption (BTS, 2001).

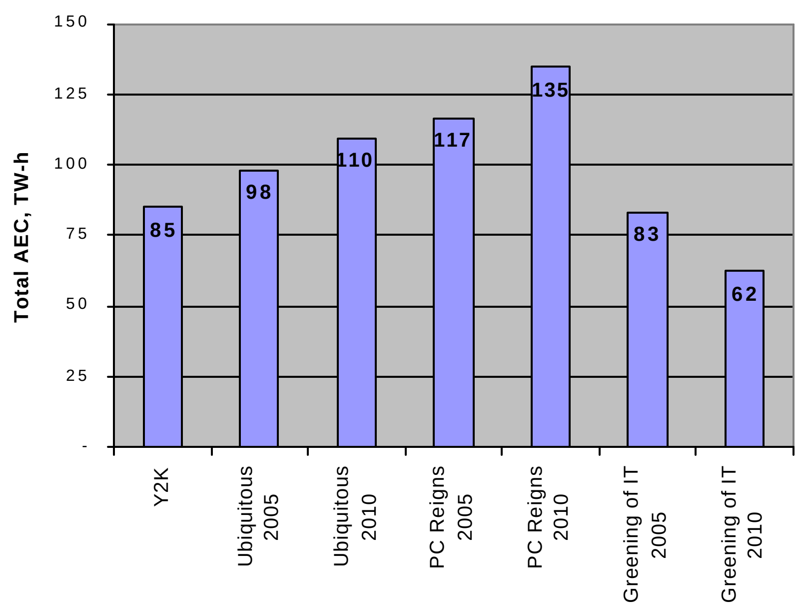

Figure 2-2: Comparison of Office and Telecommunications Equipment Annual Energy Consumption in Different Scenarios (Key Equipment Types *Only*)

PCs, monitors, and server computers continue to dominate office and telecommunications equipment electricity consumption in all three scenarios (see Figure 2-3). Telephone networks show aggressive growth in all three scenarios, primarily from continued deployment of fiber optic terminals and wireless cell site transmitters.

[4] Assuming 2% growth in national electricity consumption from Y2000 to Y2010, and the same ratio of "key equipment" AEC to "total" AEC, i.e., 97/85 = 1.14.

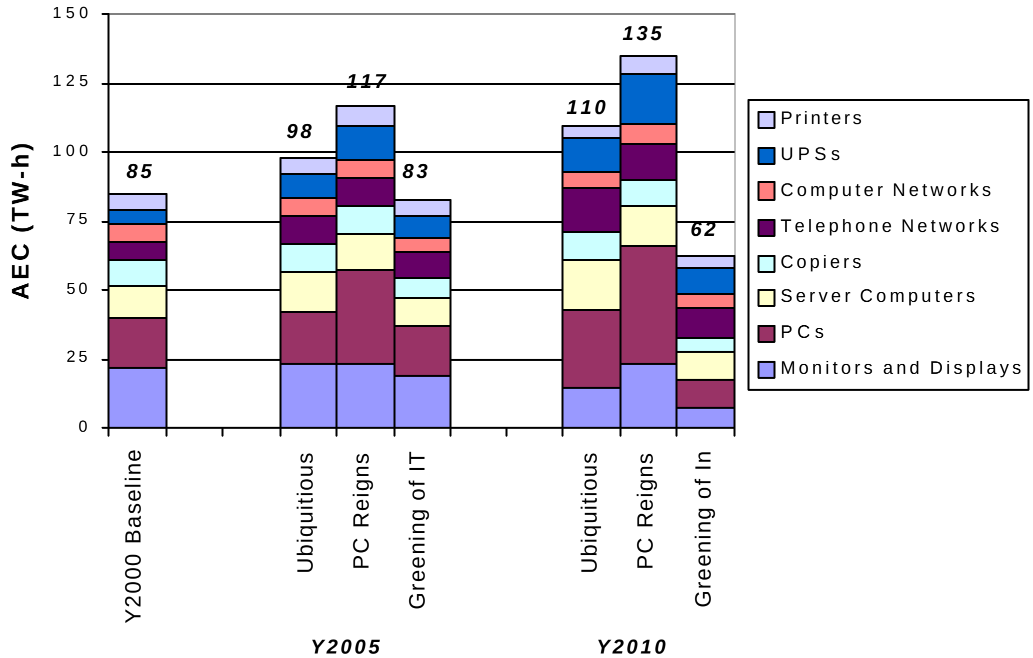

Figure 2-3: Key Equipment Type Projected Annual Energy Consumption, by Scenario

The EIA (2001b) projected growth rates for office equipment and PCs – but not telecom and computer network equipment - exceed the growth rates resulting from *all* of the scenarios (see Figure 2-4). Only the "PC Reigns" Y2005 case approaches the EIA rate over that period. The wide range of future AEC growth rates generated by the scenarios suggests that the EIA should consider a broad range of "high" and "low" cases when developing future AEC projections for PCs and office equipment.

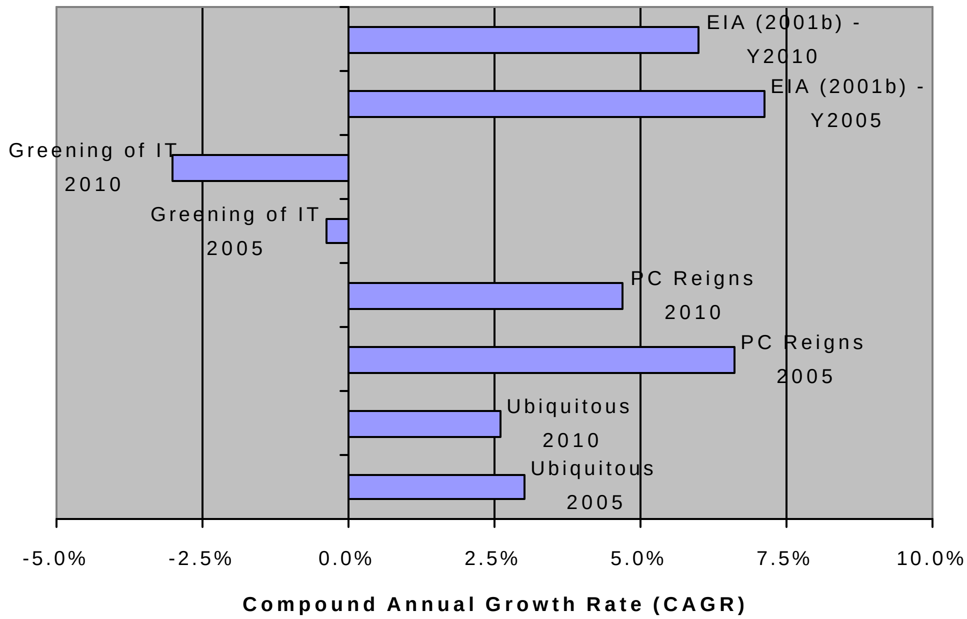

Figure 2-4: Scenario Electricity Consumption Compound Annual Growth Rates (Key Equipment Types *Only*)

Comparison of Current Office and Telecommunication Equipment Electricity Consumption Study to Other Recent Studies

Compared to recent studies of office and telecommunications equipment electricity consumption, the ADL study AEC exceeds that of Kawamoto et al. (2001) by about 20%, but equals less than 20% of that found by Mills (1999) (percentages are for similar equipment types[5]; raw values[6] shown in Figure 2-5).

[5] Similar equipment with Kawamoto et al. (2001): PCs (desktop and laptop), monitors, general displays, laser printers, inkjet/dot matrix printers, copy machines, server/mainframe/mini computers, data storage, facsimile machines, computer network equipment. Similar equipment with Mills (1999): PCs, workstations, server computers, telephone networks, routers; possibly monitors and printers (unclear if included in Mills).

[6] The Mills (1999) data reflects a linear extrapolation of his values for internet-related equipment to his entire installed base of equipment; see Section 6.3 for a more complete explanation and calculations.

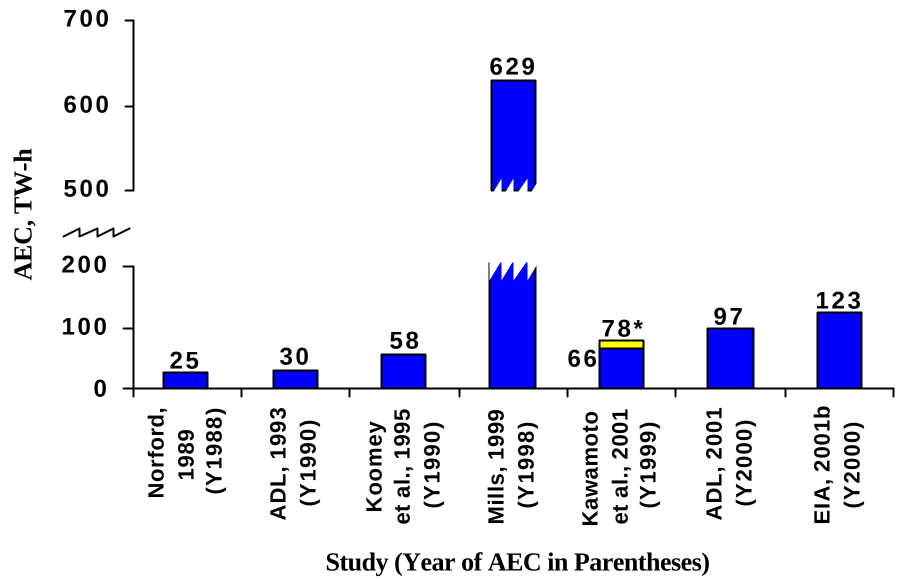

Figure 2-5: Comparison of Office and Telecommunications Equipment Annual Energy Consumption by Various Studies[7]

Two reasons are responsible for most of the differences between the ADL and Kawamoto et al. (2001) studies. First, the ADL study incorporated more recent device night status data that showed higher "on" rates and lower "ENERGY STAR®-enabled" rates than Kawamoto et al. (2001). This resulted in much higher unit energy consumption values for monitors, PCs, printers, and copiers. Second, the ADL accessed additional industry data sources that provided a more refined breakdown for most equipment types.

Mills (1999) exceeded the ADL (and all other researcher's) AEC values for all equipment types considered by consistently applying extremely high power draw devices to the entire class of equipment. For example, Mills (1999) assumed that Internet backbone routers drawing ~1,000W are representative of the entire U.S. router stock. In reality, most routers are edge routers that draw ~15W. Unfortunately, the repeated application of very high equipment power draw levels by Mills (1999) made meaningful comparisons with the current study difficult.

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[7] The 66 TW-h value reflects that shown in Kawamoto et al. (2001).

* The 78TW-h value shown for Kawamoto et al. (2001) equals the sum of the Kawamoto et al. (2001) value and the telephone central office (CO) AEC estimate of 12TW-h from Koomey et al. (1999).

It is not readily apparent why the EIA (2001b) AEC estimate, which does not include telecom and computer network equipment, exceeds that of the current study.

Indirect Impacts of Office and Telecommunication Equipment Energy Consumption

In addition to its direct impact upon electricity consumption, office and telecommunications equipment indirectly impact national energy consumption and the environment in several ways (discussed in the following paragraphs). A very preliminary consideration of the indirect impact of office and telecommunications equipment upon national energy consumption shows that the sum of the impacts is at least of the same order of magnitude as the direct energy consumption of the equipment. The direction of the net impact (i.e., an increase or decrease) remains unclear and requires further, more thorough analysis.

The heat dissipated by office and telecommunications equipment affects both building cooling and heating loads and its magnitude depends upon the building type and geographical location. During the cooling season, the heat dissipated by office and telecommunications equipment increases air conditioning loads by 0.2kW to 0.5kW per kW of office and telecommunications equipment power draw. In contrast, during the heating season it effectively displaces a portion of the heating load, i.e., each Btu of heat dissipation eliminates about one Btu of heating demand. On the balance, the equipment most likely leads to a net increase in HVAC loads, due to the concentration of office equipment in office buildings. Office and telecommunications equipment also increases peak power demand in at least three ways. First, equipment power draw during peak periods increases peak power demand. Second, the heat dissipated by office and telecommunications equipment during periods of peak demand increases peak air-conditioning loads generated by the office and telecommunications equipment. Third, the low power factors of much office and telecommunications equipment increase power demand as well as transmission and distribution losses, increasing the amount of power generation required at the plant. Overall, office and telecommunications equipment likely increases the peak power demand in a given region of the country by 3 to 4%.

An input-output economic-environmental model developed at Carnegie Mellon University estimates the total energy consumed to manufacture different categories of equipment, including the energy consumed throughout the supply chain to produce the equipment. This approach reveals that the energy consumed to manufacture office and telecommunications equipment in one year is of the same magnitude as the energy directly consumed during operation of the devices each year.

Office and telecommunications equipment could have a measurable impact upon national energy consumption by enhancing economy-wide productivity to improve the sustainable growth rate and improving the efficiency of energy utilization. The net impact could be an acceleration of the decrease of the ratio of energy consumption per $ of GDP (i.e., energy intensity). For example, e-commerce between businesses and between businesses and consumers can dramatically improve back-office efficiency and improve the utilization of existing resources. In addition, office and telecommunications equipment enables telecommuting and remote information exchange, both of which may reduce national energy consumption. However, it is premature to conclude that the acceleration in the rate of energy intensity decrease that occurred in the late 1990s is permanent. Practices such as e-commerce still have minimal exploitation on the scale of the entire economy and that the eventual effect of office and telecommunications equipment upon national energy consumption remains unclear. This also suggests that it will take some time before e-commerce could have a major impact on national energy consumption. Ultimately, over a period of many years, the internet and e-commerce will likely have the most dramatic impact upon national energy consumption of any indirect impacts of office and telecommunications equipment. Similarly, structural changes in the economy from the growing importance of the less-energy intensive[8] information technology (IT) sector during the 1990s could play a future role in abating national energy intensity in the future. The dramatic downturn in 2001 suffered by IT brings into question the strength and duration of this trend.

The manufacture of a sheet of office paper consumes more than an order of magnitude more energy than electrostatically copying or printing an image on the sheet. Consequently, the energy consumed to manufacture the paper consumed by office equipment requires more energy (~20TW-h) than is consumed by operation of all copiers and printers.

Disposal of obsolete office and telecommunications equipment contributes to landfill utilization and also can pose environmental hazards, as some devices harbor sizeable quantities of toxic materials per device (e.g.., a CRT monitor and PC can contain as much as four pounds of lead). In spite of moderate increases in projected office and telecommunications equipment recycling rates, the vast majority of literally hundreds of millions of obsolete office and telecommunications devices will go into landfills over the next decade.

[8] I.e., a lower ratio of energy consumption per dollar of output.

3 Introduction

The development, acceptance and increasing usage of technology to create, process and exchange information age over the past decade has had a dramatic impact upon the consumption of electricity by office equipment in commercial buildings. The rapidly accelerating use of the Internet impacts electricity use by computers in both homes and offices, as does the infrastructure supporting the Internet (servers, routers, switches, hubs, access devices, etc.). In addition, wireless telephony has also experienced rapid growth, as have local and long-distance telephony to a lesser degree.

To support its strategic planning efforts, the Department of Energy (DOE), Office of Building Technology, State and Community Programs (BTS), contracted Arthur D. Little, Inc. (ADL) to develop an accurate assessment of the energy consumed by office and telecommunications equipment in non-residential buildings. This study critically evaluates and builds upon prior work to develop an updated energy consumption estimate for office equipment in commercial buildings. In addition, the study goes beyond prior efforts to quantify the energy consumption of the equipment supporting the Internet, i.e., computer and telecommunications network equipment. Furthermore, to help decision-makers understand how office and telecommunications energy consumption will change in the future, the study develops scenario-based forecasts of energy consumption in the years 2005 and 2010. Well beyond providing "a number", these scenarios illuminate the key drivers, trends, and technologies that will shape future energy consumption.

To realize those goals, ADL and DOE/BTS decided upon the following approach to the project:

1. Generate a list of equipment types and collect existing data from literature.

2. Develop a preliminary estimate of national energy consumption for each equipment type.

3. Select 5 to 10 equipment types for further evaluation, based upon preliminary calculations and perceived growth in future energy consumption. Ideally, the selected equipment types should represent 66% to 75% of all energy consumed by office and telecommunications equipment in the commercial buildings sector.

4. Briefly describe the 5 to 10 equipment types selected, with the intent to provide insight into how each equipment type uses energy and function in a commercial office environment, including: physical description, functions performed, and commercialization history.

5. Develop refined bottom-up estimates of national energy consumption of each selected equipment type, for Y2000 and projections for Y2005 and Y2010.

6. Compare the current results with the results of other studies.

7. Qualitatively discuss possible indirect impact of commercial office and telecommunications equipment upon energy consumption, i.e., e-commerce, building heating and cooling loads, etc.

8. Publish the findings in a report, including feedback from government and industry experts.

This report contains the methodology, results, findings, and recommendations of the study.

4 Annual Electricity Consumption Estimate Calculation Methodology and Preliminary Energy Consumption Estimates

ADL developed preliminary electricity consumption estimates for more than 30 different equipment types to guide our selections of the equipment types for more detailed study. In general, these preliminary estimates are based upon existing literature and studies retrieved at the outset of the project.

The raw magnitude of estimated electricity consumption was the primary factor used to decide whether a given equipment type is selected for more refined analysis. In addition, we also considered the likely growth in energy consumption by the equipment type (e.g., would it consume a significant quantity of energy in 2010?). Lastly, our impressions of the quality of existing data and the degree of benefit gained from further investigation (i.e., how much would additional research improve the estimate's quality, guided our equipment selections).

This section first presents the basic methodology used to develop energy consumption estimates, followed by the preliminary energy consumption estimates for all equipment types. Appendix A presents the energy consumption calculations for each of the equipment types not selected for further study, as well as technology trends that will likely impact the future energy consumption by the devices and reason(s) for excluding that equipment type from further study.

4.1 Methodology

Figure 4-1 shows the basic methodology used to develop the annual electricity consumption (AEC) estimates.

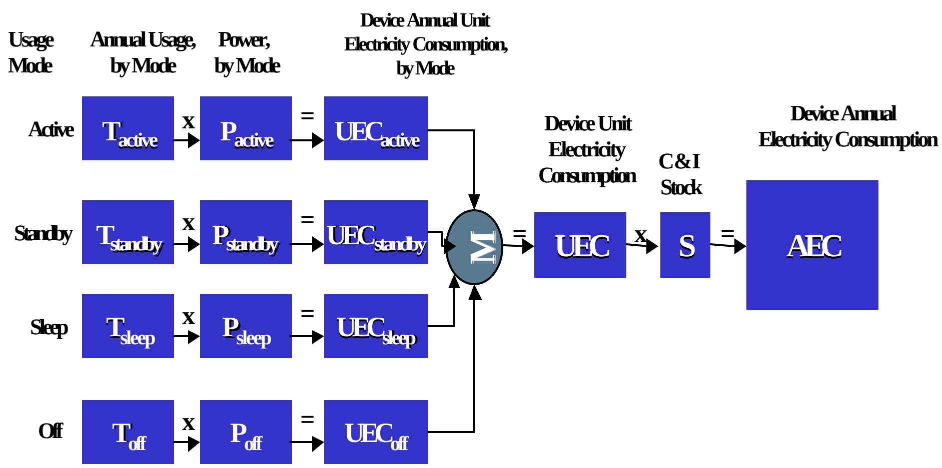


Figure 4-1: Annual Energy Consumption Methodology

First, we calculated the unit energy consumption (UEC, in kW-h) of a single device (say, a laptop PC) for an entire year. The UEC equals the sum of the products of the approximate number of hours that each device operates in a commercial building setting in each of the *t* power modes, T_m, and the power draw in each mode, P_m:

$$UEC = \sum_{m=1}^{t} P_{m,i} T_{m,i} \ ;$$

(see Section 4.1.2 for a discussion of the different operational modes). Next, we obtained or developed an estimate of the stock (i.e., installed base) of laptop computers in the commercial buildings sector, *S*. The product of the stock and the device UEC yields the total annual electricity consumption, AEC, for that equipment type:

$$AEC = UEC \cdot S \ .$$

The greater the AEC, the more relevance each equipment type has to overall office and telecommunications office equipment energy consumption and the more likely that it would warrant selection for more detailed study. For instance, our preliminary AEC estimates for laser printers and impact printers were 5.7TW-h and 1.3TW-h per year, respectively. In addition, we expect that the laser printer commercial stock will continue to grow, whereas impact printers sales have steadily declined for several years. Thus, we concluded that laser printers are more relevant to our study than impact printers and placed greater emphasis upon them in our study.

The following sections describe our approach to developing values for the different components of annual electricity consumption (AEC) calculations.

4.1.1 Commercial Building Equipment Stock

Commercial building equipment stock simply means the number of devices in use in commercial buildings. We used published equipment stocks from other studies (e.g., industry market reports, when they are available). However, many commercial stock estimates came from sales data and equipment lifetimes, simply summing the sales data over the past *y* years (where *y* represents the equipment lifetime) to develop a stock estimate. This approach has its flaws, in that relatively large (percentage-wise) errors can occur for equipment with short lifetimes, and that it does not incorporate a retirement model to effectively take into account different vintages of equipment (in contrast to ADL, 1993). To get an idea of the potential error magnitude of the summing approach, we compared an industry estimate of laser printer stock to a sum of shipment data and projections over the four-year product lifetime. Table 4-1 reveals a difference of only about 3% between the two, an error that likely is less than the error of either stock estimate.

Table 4-1: Comparison of Laser Printer Stock Estimates for Y2000

Approach	Total Stock Estimate in Thousands	Source
Industry Stock Estimate	13,926	Su (1999), projection
Sum of Shipment Data and Projections	14,381	Frasco (1999), includes projections

To determine the portion of the total stock that resides in commercial buildings, we applied a combination of household device penetration data and judgement. Each section includes an explanation of how we estimated the commercial stock of that device type.

Ideally, this study would differentiate between office and telecommunications equipment located in commercial and industrial buildings and segregate the energy consumption as such. Kawamoto et al. (2001) allocated the non-residential office equipment energy between the commercial and industrial sectors based upon commercial and conditioned industrial floor space square footage data[9]. They estimate that office equipment energy consumption is about seven times greater in commercial buildings than in industrial buildings.

We decided not to differentiate between the energy consumed in commercial and industrial buildings. First, we could not locate building equipment surveys that delineate the relative density of office equipment in commercial and industrial buildings. Although the floor space metric used by Kawamoto et al. (2001) strikes us as a plausible proxy for office equipment, it still does not address the equipment density issue for such equipment in either commercial or conditioned industrial floor spaces. Second, it is very difficult to differentiate between the usage and power draw characteristics in commercial and industrial buildings (Kawamoto et al. (2001) do not differentiate), further complicating any attempt to segregate energy consumption between commercial and industrial use. Third, properly allocating telecommunications equipment between commercial and industrial buildings becomes very difficult, and some equipment does not truly fall into either category (e.g., cell site equipment). Thus, with the blessing of DOE/BTS, we use the generic *commercial building* appellation to refer to *non-residential buildings*, because commercial buildings do appear to contain the vast bulk of office equipment stock.

The number of stock segments chosen for each equipment type depended primarily upon the energy consumption estimate accuracy gains from adding additional segments, as well as the availability of information for each segment. For example, establishing stock segments for laptop computers, PCs, small servers, and workstations was justified by the different operating patterns and energy

[9] Using data from the Commercial Buildings Energy Consumption Survey (CBECS) and DOE's Manufacturing Energy Consumption Survey (from the years 1995 and 1994, respectively), they calculated that 87.5% of all non-residential office equipment resided in commercial buildings, excepting mainframe computers, minicomputers, and terminals, which they apportioned at 90%, 75%, and 75%, respectively, based upon Koomey et al. (1995).

consumption levels of these segments. Furthermore, each segment consumes an appreciable amount of energy and effective data was available for each segment. In contrast, laptop computers were not by model and vintage, as further refinement would not have had a large impact upon the total energy consumption by office and telecommunications equipment in commercial buildings.

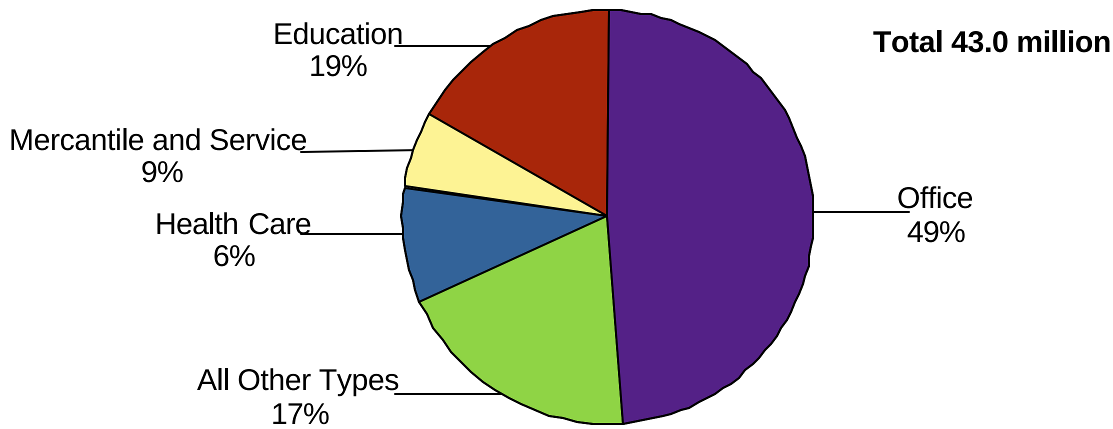
4.1.2 Usage Patterns

A device's usage pattern refers to the number of hours per week that, on average, a device operates in a given mode. Most equipment types have three distinct modes, as shown in Table 4-2. In many cases, power management (PM) strategies (such as the voluntary ENERGY STAR® program operated by the U.S. Department of Energy and the U.S. Environmental Protection Agency) and their degree of implementation have a major impact on the amount of time spent in each operating mode.

Table 4-2: Office Equipment Usage Modes

Mode Type	Description	Example
Active	Device carrying out intended operation	• Monitor displays image • Copier printing
Stand-By	Device ready to, but not, carrying out intended operation	• Monitor displays screen saver • Copier ready to print
Suspend	Device not ready to carry out intended operation, but on	• Monitor powered down but on • Copier powered down but on
Off	Device not turned on but plugged in	• Monitor off, plugged in • Copier off, plugged in

In many cases, usage pattern data came from surveys, where researchers actively monitor and record the usage pattern in a building for a period of time, ranging from days to several weeks. Usage patterns tend to have a bias towards office buildings, as most usage surveys were carried out in these building types. As shown in Figure 4-1, EIA (1998) estimates that just under half of all personal computers (PCs) found in commercial buildings in 1995 reside in offices.



Energy Information Administration
1995 Commercial Buildings Energy Consumption Survey

Figure 4-2: Distribution of PCs in Commercial Buildings, Y1995 (from EIA, 1998)

Furthermore, usage surveys tend to be expensive and therefore small in scope, making it difficult to obtain a statistically significant data set. The short lifetimes of many office and telecommunications equipment types and the rapid evolution of many equipment types makes inclusion of up-to-date patterns difficult (e.g., ENERGY STAR® enabled rates). Finally, the preponderance of studies performed in the U.S. come from the San Francisco Bay Area, introducing the possibility of a geographic/cultural bias in many surveys. Other studies performed in different European countries likely have even greater bias when used to model the behaviors in U.S. commercial buildings. When possible, we applied the relatively large data set of recent (Y2000) usage measurements made by Webber et al. (2001), which includes several types of buildings located in both the San Francisco Bay Area and Washington, D.C.

4.1.3 Power Draw by Mode

Our energy consumption estimates incorporated power draw data for different equipment types and segments for each mode of operation. Implicit in our power draw by mode data is the assumption that all of the different devices folded into a single equipment type or segment consume the same amount of energy in a given mode. For example, our model assumes that an IBM ThinkPad 560 laptop and a Compaq Armada E5000 laptop both draw 15W in "active" mode and 3W in "suspend". Clearly, this simplification is not true; however, in general, the error introduced by this assumption is on the order of or less than errors in the usage patterns and commercial stock estimates. Where available, we present as many values as possible to give insight into the potential range of power draw values by mode for each equipment type and segment.

Whenever possible, we used actual power draw measurements for the "active" power draw, as opposed to the device rated power draw. Rated power draws represent the maximum power that the device's power supply can handle and do not equal the actual power draw. Consequently, using rated power draws to estimate energy consumption most often leads to gross over-estimation of energy consumption. Table 4-3 summarizes actual-versus-rated power draw measurements of several researchers; on average, the actual power draw is about 1/3rd the rated power draw.

Table 4-3: Comparisons of Actual to Rated Power Draw

Equipment Type	Actual power draw (as a % of rated power draw)	Source
PCs	25 – 50%	Norford et al., 1989
Impact and Inkjet Printers	20 – 25%	
Computer network equipment	30%	Kunz, 1997
Computers	14 – 33%	Komor, 1997
Monitors	~28 – 85%	
Printers	~9 - 32%	
PCs	5 – 35%	Hosni, Jones, and Xu, 1999
Facsimile Machine	20 – 45%	
Network Server	50%	
Monitor	15 – 36%	

4.2 Preliminary AEC Values, All Equipment Types

Table 4-3 displays the preliminary AEC estimates, i.e., AEC values used to guide selection of equipment types for refined analysis; it also shows the final estimates (where applicable) from Section 5 to avoid confusing the preliminary and final estimates.

Table 4-4: Preliminary and Final AEC Estimates

Equipment Type	Preliminary AEC, TW-h	Final AEC, TW-h
Computers ($25k<X<$349k)	24.3	N/A[10]
Desktop Computers (< $25k)	17.7	19.2[11]
Monitors	17.9	18.8
Computers ($349k+)	9.9	N/A[12]
Laser Printers	9.3	4.6
Copiers	8.3	9.7
Server (Low-End) Computers	7.7	4.5
Telecoms Network Equipment[13]	6.4	6.6
Computer Network Equipment[14]	6.0	6.4
Point-Of-Service terminals	5.2	1.5
Display Terminals	4.1	3.4
Facsimile Machines	3.0	3.1
UPS systems	2.5	5.8
Ink Jet Printers	2.1	0.56
Impact Printers	1.3	0.37
Automated Teller Machines	0.77	0.84
Desk Top Calculators	0.68	1.7
Very Small Aperture Terminals	0.64	0.42
Scanners	0.54	0.58
Voice Mail Systems	0.33	0.19
Portable Computers	0.27	0.38
Typewriters	0.24	1.2
Desktop Dictation Equipment	0.0005	0.0005
Portable Dictation Equipment	0.0003	0.0003
Handheld Calculators	0.000023	0.000023
TOTAL	129TW-h	97-TW-h

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[10] Overlaps “mid-range” and “workhorse” server computer classes.

[11] Includes: Desktop PCs and Workstations.

[12] Overlaps “high-end” and “mid-range” server computer classes.

[13] Includes: Cell site equipment, transmission (fiber optic), public phone network, private branch exchanges, wireless phones.

[14] Includes: LAN switches, hubs, routers, WAN switches, modems/RAS, cable modem termination systems (CMTS).

Based upon the preliminary AECs magnitudes and our insight into equipment types with potential for significant AEC in 2005 and 2010, ADL, in conjunction with DOE/BTS, selected the ten equipment types shown in Table 4-4 for more refined analysis. Together, the ten equipment types consume more than 85% of the total AEC of all devices, well exceeding the 66-75% goal set for the study.

Table 4-5: Preliminary AECs of Equipment Types Selected for Refined Study

Equipment Type	Preliminary AEC, TW-h	Preliminary AEC, % of Total AEC
Computers (between $25k and $349k)	24	19%
Computers (<$25k, i.e., PCs)	18	14%
Monitors	18	14%
Computers (>$349k)	10	8%
Laser Printers	9.3	7%
Copiers	8.3	6%
Server Computers	7.7	6%
Telecommunications Network Equipment	7.1	6%
Computer Network Equipment	6.0	5%
Uninterruptable Power Supplies (UPSs)	2.5	2%
TOTALS, Selected Equipment Types	111TW-h	86%
Note: Not final values; see Section 5 for final values.		

Only one equipment type, point-of-sale (POS) terminals, consumed more energy (~5TW-h) than uninterruptable power supplies (UPSs) (~2.5TW-h), the selected device with the lowest AEC. We chose to study UPS systems instead of POS terminals for two reasons. First, UPS systems energy consumption had received minimal study in the past, whereas prior work (e.g., Koomey et al., 1995) has included POS terminals, so we believed that an analysis of UPS systems would make a more substantive contribution. Second, UPS systems exhibit potential for very strong growth in both the quantity of units and AEC due to increasing emphasis on power quality and growth in data center development. Newer POS terminals, on the other hand, have tended to show reduced energy consumption per unit (e.g., via the incorporation of liquid crystal displays [LCDs]), and have much less potential for future AEC growth.

We continued to update our AEC estimates for the equipment types not selected for refined study as we encountered useful data and actively sought improved data for those believed to consume more energy (such as POS terminals, ATMs, facsimile machines). Appendix A presents the AEC calculations for all equipment types not subject to further analysis. Section 5 contains AEC estimates for all devices, most notably equipment studied in more detail.

5 Bottom-Up Energy Consumption Estimate for Equipment: Year 2000

Commercial office and telecommunications equipment consumed about 97-TW-h of electricity in Y2000 (see Figure 5-1).

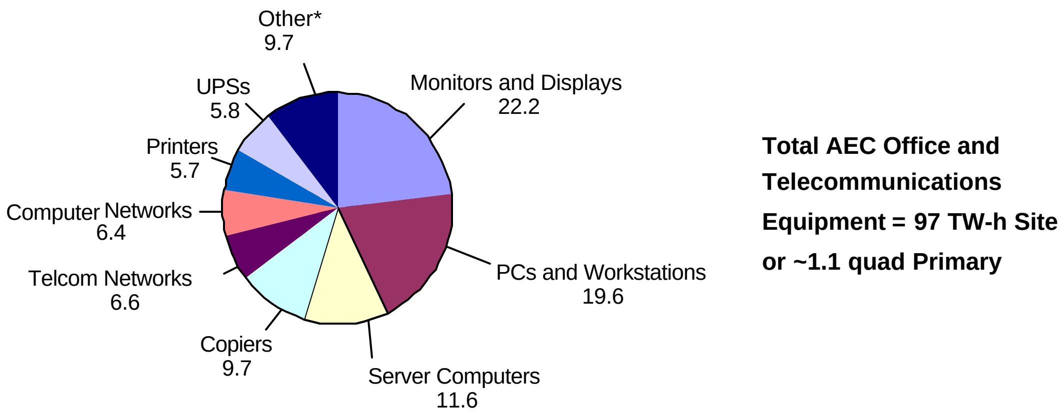

Figure 5-1: Annual electricity consumption (AEC) of Office and Telecommunications Equipment in Commercial Buildings, Y2000

Figure 5-1 also shows that personal computers and monitors/displays accounted for more than 1/3rd of the AEC and that the ten devices selected accounted for almost 90% of the device AEC in Y2000. The final AEC estimates for all equipment types studies, ranked by AEC, are presented in Table 5-1.

Table 5-1: Y2000 AEC by Equipment Type, Total of 97 TW-h

Equipment Type	AEC, TW-h	% of Total AEC	Cumulative % of Total AEC[15]
Monitors	18.8	19%	19%
PCs – Desktop	17.4	18%	37%
Copiers	9.7	10%	47%
UPSs	5.8	6%	53%
Laser Printers	4.6	5%	58%
Server - Low-End	4.5	5%	63%
General Displays	3.4	4%	66%
Server – Workhorse	3.3	3%	69%
LAN Switches (C)	3.3	3%	73%
Facsimile Machines*	3.1	3%	76%
Cell Site Equipment (T)	2.3	2%	78%
Server - Mid-Range	2.0	2%	80%
Workstations	1.8	2%	82%
Transmission (Phone) (T)	1.8	2%	84%
Desktop Calculators*	1.7	2%	86%
Hubs (C)	1.6	2%	88%
Data Storage	1.5	2%	89%
POS Terminals*	1.5	2%	91%
Typewriters*	1.2	1%	92%
Routers (C)	1.1	1%	93%
Public Phone Network (T)	1.0	1%	94%
Private Branch Exchanges (T)	1.0	1%	95%
ATMs*	0.84	1%	96%
Scanners*	0.58	1%	97%
Inkjet Printers	0.56	1%	97%
Wireless Phones* (T)	0.49	1%	98%
PCs – Laptop	0.38	0%	98%
Impact Printers	0.37	0%	99%
Server – High-End	0.37	0%	99%
Supercomputers	0.37	0%	99%
VSATs*	0.23	0%	99%
Voice Mail Systems*	0.19	0%	99%
Line and Other Printers	0.15	0%	99%
WAN Switches (C)	0.15	0%	100%
Modems / RAS* (C)	0.06	0%	100%
CMTS* (C)	0.021	0%	100%

[15] "Cumulative % of Total" does not equal sum of "% of Total" due to rounding.

* "Other" includes: Facsimile machines, desktop and handheld calculators, point-of-sale (POS) terminals, electric typewriters, automated teller machines (ATMs), scanners, very small aperture terminals (VSATs), scanners, supercomputers, voice mail systems (VMSs), smart handheld devices, and dictation equipment.

Equipment Type	AEC, TW-h	% of Total AEC	Cumulative % of Total AEC[15]
Smart Handheld Devices*	0.008	0%	100%
Dictation Equipment*	0.001	0%	100%
Handheld Calculators*	0.000023	0%	100%
*Studied in preliminary effort (see Section 4 and Appendix A) (C) – Part of Computer Network Equipment category (T) – Part of Telephone Network Equipment category			

Table B-1 (see Appendix B) presents unit electricity consumption (UEC) data for all equipment types, including breakdowns of UEC by usage mode.

The equipment underlying the communications backbone of the Internet, i.e., computer network equipment, telephone network equipment, and server computers, consumes almost 25TW-h. Placed in the context of the ~ 133 million PCs installed in the U.S. (non-residential and residential PCs; see Table 5-2), server computers and computer and telephone networks power demand equals about 21 watts per PC[16].

The following sections present equipment descriptions and AEC calculation details for the key equipment types.

5.1 Personal Computers (PCs)

5.1.1 Background

Douglas C. Engelbart, of the Stanford Research Institute, developed the first personal word-processing computer in 1969. Three years later, microprocessor-based personal computers using Intel microprocessors first became commercially available. Today, Compaq, IBM, Dell, and HP are but a few of the key companies in the PC industry.

For two decades, the personal computer (PC) has served as a vital instrument in the business world, used for numerous tasks including data entry, word processing, desktop publishing, and data analysis. Its importance has increased recently due to the commercialization of the Internet, which evolved out of the ARPANET (created in 1968). PCs now provide people access to additional modes of communication, including electronic mail, instant messaging, and web-based presentation and

[16] This represents the average power over the 8760 hours of annual computer and telephone network operation.

publishing of information and represent the primary vehicle of Internet access for the vast majority of the population.

PCs consists of a central processing unit (CPU) and hard-drive, as well as user interface devices (keyboard and mouse) and a variety of input/output devices (CD-ROMS, floppy drives, etc.). Fundamentally, computers operate on a binary logic system, meaning that all information is translated into either a “1” or a “0”. The two basics tasks carried out by PCs, running programs and storing data, operate in this fashion.

PCs run programs to carry out all sorts of tasks, be they mundane (managing the screen display or a game of solitaire), moderately sophisticated (word processing and spreadsheet programs) or extremely complex, (fluid flow simulation or data processing programs). To run a program, the PC reads the program code into the Random Access Memory (RAM), where the microprocessor executes the instructions in the program code. The size of the RAM determines the size of program that a given PC can run. For example, a PC used for word processing may require only 32MB of RAM, while elaborate fluid flow simulations can easily demand gigabytes of RAM to run effectively. The speed of the central processing unit (CPU) impacts the rate at which the computer can execute a given program, which is particularly important when dealing with complex graphics and design software. The processor speed represents the number of times the gates within the microchip can switch in a given period of time, e.g., a 500 MHz processor can complete 500,000,000 gate cycles in one second. Fundamentally, each gate cycle represents the switching of a transistor between “hi” voltage (a “1”) and “low” voltage (a “0”). Processor speeds has increased at a consistent dramatic pace over the past 30 years, doubling in speed approximately every two years while the price of each processor remained essentially constant; this principal is known as Moore’s Law. Consequently, the *price per unit* of processing power has dropped by a factor of approximately *10,000* over the past 30 years! It is this remarkable progress that has made the PC ubiquitous and has enabled PCs to perform data-intensive functions carried out by mini- or mainframe-computers in the past.

Experts (Mann, 2000) are optimistic that semiconductor manufacturers will find technical solutions to enable Moore’s Law to hold to at least 2005, as the line distance between transistors continues to decrease. Beyond that, however, the future rate of progress remains unclear as the current chip-producing technology approaches its physical limits and the price of new chip fabrication plants becomes potentially cost-prohibitive.

Computers store data in three ways, either to a hard drive installed in the computer, to external drives, or by sending it to a storage device on the network. Hard drives are read-only memory (ROM), meaning that they cannot execute programs. Instead, they store data, be it the document produced by a word processing program, a digital image, or the raw data output of a data processing program. The data storage capacity is quantified by the number of bytes[17] that the drive can store; a Y2000 vintage PC comes with roughly an 8GB hard drive or, in some instances, multiple hard drives. External drives, including floppy, CD-ROM, ZIP™, etc., transfer data between an external disc and the computer's hard drive(s). Computers transfer files to network file servers via local area networks (LANs), wide area networks (WANs) or the Internet, where the files are saved in different types of storage media.

In the past several years, very limited portions of PC functionality have begun to migrate to other, typically handheld devices equipped with some capabilities of PCs, such as smart handheld devices (e.g., Palm Pilot) and 2.5G and 3G mobile phones.

5.1.2 Personal Computer and Workstation Stocks

Personal computer stock estimates for desktop and laptop devices were derived from two sources of shipment quantities: the ITIC Databook (2000) and Akatsu et al. (1999). Table 5-2 presents these data, spanning the three-year lifetime estimate for PCs (ERP, 1999). Ultimately, commercial stock estimates were based on Akatsu et al. (1999) because they segregate laptop and desktop shipment data. To calculate the desktop and laptop computer stock segregation, we calculated the residential PC stock and subtracted it from the total PC stock (see Table 5-3). A demographically-representative 48,000-household survey carried out by NTIA (2000) estimates that in August, 2000, 51% of the approximately 105 million households in the U.S. have at least one computer. We accounted for households possessing multiple computers by assuming that the percentage of computer-owning households with multiple computers in Y2000 was the same as in 1997 (i.e., ~16.6% [EIA, 1997]) and that all of those households had a two computers. This yields the approximate residential stock of desktop and laptop PCs. Finally, we assumed that laptops and desktops represented the same portions of both the commercial and residential stocks, about 17% and 83%, respectively.

[17] A byte equals 8 bits, where a bit equals a single 1 or 0.

Table 5-2: PC Sales Data

Year and PC Type	Units sold, thousands, from ITIC (2000)	Units sold, thousands, from Akatsu et al. (1999)	Notes
Desktop[18]	125,885		
1998	36,700	29,034	
1999	44,290	37,477	
2000	48,960	43,898	
Laptop			Does not include ultra-portables
1998		6,398	
1999		7,736	
2000		8,887	

Table 5-3: PC Stock Calculations

Stock Segregation Calculations	Value	Comments
Total Desktop Stock, Commercial and Residential	110,409,000	Akatsu et al. (1999) data
Total Laptop Stock, Commercial and Residential	23,021,000	Akatsu et al. (1999) data
Percent of Residences with a Computer	51%	From NTIA (2000); ~105 million households in the U.S. in Y2000.
Percent of Residences with a Computer, with Multiple Computers	16.6%	From EIA (1997); Assumed each residence had two computers[19].
Residential Stock, Desktop and Portable Computers	62,600,000	Result: 47% of Laptop and Desktop PCs in Residences
Laptop Commercial Stock	12,216,000	Assumed the same % of laptops and desktops in the commercial sector
Desktop Commercial Stock	58,591,000	Assumed the same % of laptops and desktops in the commercial sector

The total of about 71 million PCs (desktop and laptop) exceeds the EIA (2001a) preliminary estimate of 56,926,000 computers in commercial buildings in 1999 by 25%. About half of the difference likely reflects the fact that our stock also includes PCs in industrial buildings[20]. Boedecker (2001) suggests that the CBECS survey used by the EIA to generate their PC estimate may have led many respondents to not include laptop computers. Consequently, the assumption that the EIA (2001a)

[18] The ITIC (2000) shipment numbers for desktop computers also include laptop and workstation shipments.

[19] The Residential Energy Consumption Survey (RECS) from 1997 found that 35.5 million households have one computer and 5.9 million households have more than one computer, which translates into 5.9/35.5= 16.6% of all households with computers had more than one computer. We assumed that percentage remained the same in 2000.

[20] Kawamoto et al. (2001) estimate that 87.5% of non-residential PCs operate in commercial buildings, a ratio that scales the EIA estimate up to 65 million PCs.

stock includes only desktop computers eliminates most of the difference in stock estimates.

5.1.3 Personal Computer AEC Calculations

Several investigators have reported power draw values for PCs as a function of mode, as summarized in Table 5-4.

Table 5-4: PC Power Draw Measurements

PC	Power Draw, Watts					
PC Type	**Active**	**Standby**	**Suspend**	**Off**	**Unplugged**	**Sources/Notes**
Desktop	55	N/A	25	1.5	0	Kawamoto et al. (2001)
Laptop	15	N/A	3	2	0	Kawamoto et al. (2001)
Pentium II	55	49	32	2	0	Meyer and Schaltegger (1999)
486	36	0	22	2	0	MACEBUR (1998)
Based on 386, 486, and Pentium	55	N/A	20[21]	N/A	N/A	Wilkins & Hosni (2000)
Pentium	51		26	1	0	MACEBUR (1998)

Kawamoto et al. (2001) defined only three modes of use and defined the "suspend" power as "low power". Table 5-5 lists the corresponding usage patterns by mode in hours per year.

Table 5-5: PC Usage Time Data

Type	Active	Standby	Suspend	Off	Unplugged	Source
LBL Desktop Average	3,395	N/A	798	4,568		Kawamoto et al. (2001)
LBL Laptop Average	1,001	N/A	3,191	N/A	4,568	Kawamoto et al. (2001)
Pentium II w/PM	782	391	1,304	3,780	2,502	Meyer & Shaltegger (1999)
Pentium II w/o PM	2,477	0	0	3,780	2,502	Meyer & Schaltegger (1999)
486	1,051	0	876	3,854	2,978	MACEBUR (1998)
Pentium	1,402	0	350	4,730	2,277	MACEBUR (1998)

[21] Defined as energy-saver mode.

The desktop and laptop PC unit energy consumption (UEC) calculation (see Table 5-6) incorporates the most appropriate power draw data selected from Table 5-4, as well as detailed usage information (see Tables G-1 through G-5 in Appendix G).

Table 5-6: Desktop and Laptop Unit Energy Consumption (UEC) Calculations

Type	Active	Suspend	Off	Unplugged	Source
Power Consumption, Pentium Desktop (W)	55	25	1.5	0	Kawamoto et al. (2001)
Usage Time, Pentium–Class Desktop (h/year)	5,131	375	3,254	0	Webber et al. (2001), Nordman et al.(2000), Kawamoto et al. (2001)
Power Consumption, Laptop (W)	15	3	2	0	Kawamoto et al. (2001); Compaq Armada E500 Average Operating Power[22]
Usage Time, Laptop (h/year)	1,001	4,505	1,627	1,627	Kawamoto et al. (2001), Webber et al. (2001), and Nordman et al. (2000)
DESKTOP Total UEC (kW-h/year)					297
LAPTOP Total UEC (kW-h/year)					32

The remarkable difference in hours spent in "active" mode between laptop and desktop PCs reflects the 100% and 25% ENERGY STAR®-enabled rates for the devices.

Table 5-7 summarizes the total annual electricity consumption (AEC) for desktop and laptop PCs.

Table 5-7: PC AEC Calculations

Type	Commercial Stock	UEC (kW hrs / year)
Desktop	58,591,000	297
Laptop	12,216,000	32
TOTAL PC Energy Consumption (TW-h)	17.8	

[22] SeeTechnical Specifications at: www.compaq.com .

5.1.4 Workstations AEC Calculations

Workstation computers are more powerful machines than PCs that fulfill the requirements of computationally-intensive applications, such as CAD, computational fluid dynamics (CFD), etc. As such, workstations often have multiple processors to expedite calculations, augmented RAM to efficiently run larger programs/problems, and additional memory to store program outputs. Physically, workstations resemble desktop PC towers, albeit somewhat larger in profile.

Copeland et al. (1999) reported an installed base of workstations of 2,553,829 units all of which we assumed operate in commercial buildings. Workstation power draw estimates by mode were derived from manufacturers' published literature (see sources in Table 5-8) and approximate actual-to-nameplate power ratios. We assumed a 33% power ratio, the high end of the range actual-to-nameplate ratios (9 to 33%) found by Wilkins and Hosni (2000) for 486 and Pentium-class computers. Table 5-8 summarizes the power draw data.

Table 5-8: Workstation Power Draw Estimates

Type	Nameplate[23], Watts	Actual[24] Active Power Draw, Watts	Source
Dell Workstation 330[25]	330	110	Dell.com
Compaq Workstation APP 550	375	125	Compaq.com
Compaq Workstation SP 750	475	158	Compaq.com
SGI 230[26]	428	143	Sgi.com
Average Active Power Draw		*134*	

Based upon the active power draw values, the power draw in suspend and off modes was estimated by applying the same active-to-suspend mode draw ratios as personal computers. Thus, a workstation in suspend mode draws about 60W, using a desktop computer active-to-suspend power ratio of 0.45. Off power draw is 2W, similar to the desktop off-mode power draw. Finally, we assumed that workstations have the same usage patterns (and PM-enabled rates) as desktop computers. This equates to an annual electricity consumption of 1.8TW-h (see Table 5-9).

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[23] Data from the manufacturer.

[24] ADL estimate, assuming 1/3rd the nameplate power-draw.

[25] See http://www.dell.com/us/en/biz/products/model_precn_3_precn_330.htm

[26] See http://www.sgi.com/workstations/230/techinfo.html

Table 5-9: Workstation AEC Calculations

Installed Base, in thousands	Mode	Modal Use, h/Year	Modal Draw, Watts	Total Annual electricity consumption, TW-h
2,554	Active	5,131	134	1.8
	Suspend	375	60	
	Off	3,254	2	

5.2 Server Computers

In today's usage, a "server" generally refers to a computer that is not directly associated with a specific human user. Servers instead provide common functions to a group of users, or perform back-end processing invoked on a scheduled basis or by other computers.

Servers vary over a wide range of sizes. At the upper end are the traditional mainframes, repositioned as "high-end" servers. The market segment formerly called minicomputers is now classified as a "midrange" or "workhorse" server (e.g, IBM now calls its AS/400 family the "eserver iSeries"). Compaq's high-end Alpha-based computers, which replaced the VAX family that it inherited from Digital Equipment Corporation, have been re-branded as AlphaServers. Compaq now also classifies the large fault-tolerant computers inherited from Tandem as servers. These high-end computers are generally fairly large and rack-mounted or freestanding in cabinets that range from the size of a deskside computer to refrigerator size.

Server functions run the gamut of computing tasks, with the obvious exception of those that involve direct human interaction (such as display management). High-end servers often carry out traditional batch processing applications, such as billing, or fulfill high-volume transaction processing applications, such as banking and airline reservations. Mid-range servers typically handle database applications, and can be the main back-end computers for medium-sized businesses. These larger systems often feature superior reliability relative to PC-derived systems, and often have very large storage and input/output handling capacity. Low-end servers more frequently take on tasks that require smaller storage and/or lower criticality, for example for LAN file and print management. Many perform as web servers at large hosting centers (also known as server farms, data centers, co-location facilities, etc.) operated by Internet service providers (ISPs). Other common roles of low-end servers include e-mail servers or lower-volume specialized application servers.

Servers continue in the oldest part of the computing industry and are similar to the non-interactive machines dating back to early mainframes. They have evolved out of mainframes, minicomputers, workstations and PCs, with their CPU power, memory and disk storage capacity all growing rapidly on or near the "Moore's Law" curve. In general, software expands to take up additional capacity, so a similar number of users are supported by a $5,000 server today running Windows 2000 as were supported by a $5,000 server of 1995 running Windows NT 3.51.

The following sections discuss the "high-end", "mid-range", and "low-end" servers and their histories and energy consumption, in more detail. Two additional sections on related equipment, specifically supercomputers and data storage devices, follow.

5.2.1 High-End Server Computers

High-end server computers evolved from (and continue to include) the class of computers formerly known as mainframe computers. In a generic sense, mainframes circa Y2000 fulfill the role of application servers, database servers and transaction processing. They are large systems, deployed in data centers, which typically process high volumes of data, for example, batch processing (no direct human interaction) and on-line transaction processing (dedicated application terminals), and are the backbone of the financial services industries. The mainframe industry declined in the late 1980s and early 1990s, leading to an industry shakeout that IBM survived with a larger market share while most of its traditional competitors exited the business, or merely now sell "servers". Most mainframes have been re-branded as servers (e.g., the newest member of IBM's high-end S/390 family is called a "zServer"), while other high-end members are called "Parallel Enterprise Servers." Nonetheless, many high-end servers remain in use in traditional mainframe applications.

Generally, end-users purchase high-end servers because they need to handle vast quantities of data in a highly reliable, predictable, fashion. Thus, they fulfill applications such as billing, airline reservations, and banking, where the loads tend to be predictable and relatively consistent. In addition, they often host large data bases and carry out database-intensive applications such as "data mining". Their internal design caters to these applications by virtue of having many times the I/O bandwidth of smaller systems. high-end servers may use dedicated processors ("channels") to interface to peripherals, with a large degree of internal data path parallelism. Overall, the main processor takes on the role of both "traffic cop" and "number cruncher". Akin to mainframes, high-end server designs enable many systems modifications without interrupting service (i.e., operators can add peripherals and even processors to running systems), while the operating systems insulate tasks from one another via virtual machines. The ability of high-end servers to effectively partition the machine into numerous virtual machines offers many benefits in server applications. For example, a high-end server can simultaneously provide web presence for multiple companies while dynamically allocating more or less capacity to specific sites as demand flows and ebbs.

Traditionally, mainframe computers occupied multiple cabinets and often filled a room. Today's high-end server variants tend to be smaller, commonly fitting into a single tall cabinet, but still larger than other types of computing equipment. Mainframe applications tend to be input/output (I/O) intensive, rather than computationally-intensive. Consequently, large numbers of peripherals, including disk drives, tape drives (nowadays usually a cartridge of some sort), high-speed printers, and network controllers (traditionally called "front-end processors") typically accompany high-end servers.

Mainframe computers have always pushed up against the limits of cooling and power circuitry. Early 1950s systems used vacuum tubes, then progressed to discrete transistors. The classic IBM mainframes of the late 1960s into the 1980s implemented emitter-coupled logic (ECL), the most power-consumptive semiconductor technology, and, in some instances, used water cooling. In the past, some IBM systems even used 400 Hz power supplies behind motor-generator sets, because 60 Hz supplies were too inefficient at the high-current loads required. CMOS semiconductors overtook ECL around 1990 and substantially decreased mainframes' power draws. Today's high-end servers are air cooled, largely based around specialized microprocessors, or clusters of microprocessors, and are distinguished more by their peripherals, huge memory (up to 64 GB of RAM), and I/O capacity than by their actual processing speed. Some users deploy high-end servers in clusters to handle higher loads.

5.2.2 Workhorse and Mid-Range Server Computers

Forrester (1999) refers to computers in the price range formerly occupied by minicomputers and low-end mainframes as workshorse ($20K-99K units) and mid-range servers ($100-999K). Minicomputers, a sector that once occupied a major portion of the computer industry, have faded from common use in recent years. As a class, minicomputers evolved before microprocessors, and thus referred to all computers smaller than mainframes. Later, microprocessor-based systems entered the market at lower price points, leaving minicomputers in a narrowing range between micro and mainframe. Eventually all of the minicomputer companies either went out of business or evolved into the "workstation" and "server" sectors; in essence, the "minicomputer" sector no longer exists in today's market. Nonetheless, many midrange servers are the modern equivalent of the minicomputer, serving files and applications.

Physically, minicomputers typically occupied all or part of a rack or rack-sized cabinet. A related sector, the "superminicomputer", attained popularity in the 1980s (notably the DEC VAX); these could reside in larger cabinets. Minicomputers thus overlapped the low end of the mainframe range, differing largely in the software they ran and in their internal I/O architecture. Users generally accessed minicomputers via asynchronous terminals, which gave their users more flexibility than the application-bound terminals frequently used with mainframes. Because companies designed minicomputers for use outside of the traditional data center, minicomputers generally used ordinary (117V) power, though they often had sensitive cooling requirements. Superminis tended to use 230V power and were located in data centers.

Minicomputers found widespread use as embedded controllers, before microprocessors took their place beginning in the 1970s. They also played a major role in interactive computing, as schools and small businesses could better afford minicomputers; early "office automation" was largely a minicomputer application. During their heyday in the 1980s, many were sold as "departmental computers", to distinguish them from the systems (usually mainframes) owned by corporate MIS departments. The Unix operating system, nowadays very popular for servers and high-end desktops, began on Digital Equipment Corporation (DEC) minicomputers in 1969. Computer networking also largely developed on minicomputers, which used networks to be competitive with mainframes, though DEC mainframes played a large role in the early ARPANET as well.

The minicomputer industry began in the 1960s, led by DEC, whose PDP-8, a 12-bit mini, made its commercial debut in 1965. It grew wildly in the 1970s as minis challenged mainframes for new applications. However, just as minis attacked mainframes from below, PC-type desktop systems challenged them from below, and minicomputers declined rapidly beginning in the late 1980s. Some systems (e.g., IBM's AS/400) were better positioned as database servers and thus survived, but microprocessor-based servers replaced general-purpose minis.

5.2.3 Low-End Server Computers

Low-end servers are generally based on standard PC architecture, or on workstations (e.g., Sun Sparc), but with different packaging. Some reside in desk-side tower cases, but many are rack-mounted. The current trend is to specify the size of servers in Rack Units (one Rack Unit, or RU, equals 1¾ inches in height). Small 1RU servers have increasingly grown in popularity, especially for ISPs who want to maximize the use of floor space in co-location rooms[27]. For example, Compaq's 1RU ProLiant DL320 uses a Pentium III processor and fits up to two disk drives and 2 GB of memory. The power supply has a 180 W rated capacity. This solution suffices for mid-sized web server applications. In contrast, corporate file and application servers often use larger packages, which allow for more internal expansion, including multiple processors.

Low-end servers more frequently take on tasks that require smaller storage and/or lower criticality; for example, LAN file and print servers running Novell Netware or

[27] A co-location facility operator houses large quantities of servers and network equipment for a wide range of clients, including Internet service providers (ISPs) and companies with web presence, "co-located" in the same facility.

Windows NT. The growth of the Internet has led to a surge in the number of small Web servers deployed, typically in "server farms." This followed the widespread adoption of LAN servers across the corporate landscape in the late 1980s and early 1990s. Other common roles of low-end servers include e-mail servers or lower-volume specialized application servers. Low-end servers are more likely to run a free operating system such as Linux or BSD Unix. Commercial forms of Unix, such as Sun's Solaris, play an important role in the upper portions of this range (i.e., servers over $5K), where greater vendor support and reliability outweigh price.

5.2.4 Server Computer Stocks

Josselyn et al. (2000) separate server computers into eleven price bands. We categorize these into four sections because of an additional data source, Forrester (1999), which defines and lists representative models for four categories of servers. Tables 5-10 and 5-11 display the estimated lifetime and shipments of the servers in the four classes, respectively. We assume that all server computers reside in commercial buildings.

Table 5-10: Server Lifetime Estimates, by Class

Category	Lifetime, Years	Source
Low-end	3	ADL Estimate
Work-horse	5	ADL Estimate
Mid-range	5	EPR (1999) and ADL Estimate
High-end	7	EPR (1999) and ADL Estimate

Table 5-11: Server Shipment Data by Class (from Josselyn et al., 2000)

Year	Low-end (<$24.9K)	Work-horse ($25K<X<$99.9K)	Mid-range ($100K<X<$999K)	High-end ($1,000K+)
1994				2,100[28]
1995				2,200[29]
1996		95,619	33,897	1,896
1997		136,827	31,831	2,328
1998	1,082,180	104,776	37,813	2,852
1999	1,367,839	119,641	40,340	2,663
2000	1,615,126	121,097	41,314	2,510
TOTAL Stock	4,065,145	577,960	185,195	16,549

Manufacturers' literature provided rated power draw information for representative server computers in each class; in practice, the actual power draws fall are less than

[28] Back-casted, based upon linear trend.

[29] Back-casted, based upon linear trend.

the rated values. Hosni et al. (1999) found that the measured power draw of a "network server[30]" equaled about 50% of the nameplate power. Personnel from Silicon Graphics (Davis, 2001) and Dell Computer (Dell, 2001) estimated that the servers actually consumed 50-75% of the published nameplate value. Independent laboratory measurements presented by Hipp (2001) for low-end servers (Table 5-12) indicate that the ratio is closer to 50%, and we decided to use an estimate of 50% of the nameplate design for calculation of the actual draw.

Table 5-12: Measured Low-End Server Power Draw Data (from Hipp, 2001)

Machine	Rated Power Draw, W[31]	Measured Power Draw, W	Ratio of Measured to Actual Power Draw, %	Notes
Compaq DL320	180 (Power Supply Rating)	76.4	42%	
Sun Cobalt 4I	60W (Maximum)	33.9	57%	Compared to Sun Cobalt RaQ4 Server Appliance
Sun Cobalt 4R XTR	133W (Maximum)	72.0	54%	Compared to Sun Cobalt RaQ XTR

Table 5-13 lists the representative server models identified by Forrester (1999) for each category and their nameplate and our estimate of actual power draw.

Table 5-13: Representative Server Power Draw Values

Manufacturer	Sample Model	Category	Max Draw, Watts	Average Draw, Watts
Compaq	Proliant 330	Low-end	250[32]	125
Compaq	ES 40	Work-horse	1,300[33]	650
Compaq	GS 60E	Midrange	2,450[34]	1,225
IBM	S/390 Multiprise 2000[35]	High-end	N/A	2,000[36]
IBM	E410	High-end	5,040[37]	2,520

[30] Average draw of 336W versus 680W nameplate rating, suggesting a workhorse-class server.

[31] From manufacturers' web sites

[32] See http://www.compaq.com/products/quickspecs/10523_div/10523_div.html#TechSpecs

[33] Data from the compaq.com web site.

[34] Data from the compaq.com web site.

[35] Not used for AEC calculation.

[36] From Kawamoto et al., 2001; does not include peripherals (e.g., tape drives)

[37] Data from the ibm.com web site.

A single power draw number for high-end servers proved difficult to estimate due to the recent evolution of high-end server processor technology. Until rather recently, high-end servers or "mainframes" typically consumed much more energy than the values listed in Table 5-13, due to the common use of emitter-coupler logic (ECL) technology. ECL-based mainframes created such a high level of heat dissipation that many older mainframe computers required liquid cooling to avoid over-heating. For example, Koomey et al. (1995) report that a 1985 or 1990 vintage mainframe computer draws between 12,500W (standby) and 25,000W (active), close to an order of magnitude more power than current machines. More recently, Meyer and Schaltegger (1999) estimated that a larger mainframe computer[38] consumes 30kW.

According to Boyes (2001), mainframe computers using ECL technology have largely been retired in favor of machines using more efficient complementary metal oxide semiconductor (CMOS) technology, which first appeared in large IBM mainframes in 1994, for two primary reasons. First and foremost, the market-leader IBM very aggressively pursued upgrades and replacements for the older mainframes. They augmented this strategy by increasing maintenance costs on them to prohibitive levels and not making older operating systems compatible with the newer applications. Second, the cost of managing the "Y2k" issue accelerated the retirement of older mainframes in favor of recent, Y2k-compliant CMOS-based mainframes. A report by the National Safety Council (1999) on the recycling rates of mainframe computers supports this view. They estimate that more than 50,000 mainframe computers[39] were recycled each year in both 1997 and 1998, relative to annual mainframe shipments of about 12,000 per year - almost all of the entire mainframe computer stock turned over in the late 1990s. This finding buttresses our argument and our confidence in using the more recent 2.5kW power draw value to model high-end server energy consumption. Nonetheless, the potential for sizeable errors in high-end server energy consumption remains.[40]

Server computers typically operate in active mode around the clock (i.e., 24 hours per day, 7 days a week, 365 days per year, or all 8,760 hours per year). Table 5-14 presents the AECs for each server band.

Table 5-14: Server Computer AEC

Server Category	AEC (TW-h)
Low, <$24.9K	4.5
Work-horse, $25-99.9K	3.3
Mid-range, $100-999K	2.0
High-end, $1,000K+	0.4

[38] Interpretation of German "Grossrechner".

[39] Their definition includes some computers in the "mid-range" category.

[40] For instance, if only 10% of the high-end stock draws 10kW, the high-end server AEC would increase by 30%.

5.2.5 Supercomputers

Supercomputers are the most powerful computational devices in the world, consisting of hundred or even thousands of processors coupled with extensive memory to enable them to run the largest programs efficiently. Weather and climate modeling, complex fluid flows, biological phenomena (e.g., protein and molecular structure and movement), and nuclear explosion simulation represent only a few of the problems tackled via supercomputers. The specifications for the Cray T3E supercomputer provide a basic feel for the potency of these machines (see Table 5-15).

Table 5-15: Cray T3E Supercomputer Specifications

Characteristic	Specification
Peak Performance	54 to 3,000 GFLOPS
Total System Memory	10 to 1,000GB
Peak Bisection Bandwidth	42 to 166GB/s
Cabinet Footprint Area	35.4 to 229.6 ft^3

As a class, supercomputers constitute a minute portion of the computer market, with an installed base of only about 205 machines (Willard et al., 2000; see Table 5-16).

Table 5-16: Supercomputer Stock (from Willard et al., 2000)

Supercomputer Models	Installed Base
Cray T3E	40
Other (e.g., Cray T-90)	165
Total	205

On the other hand, their immense computational power translates into extreme power demands, with the Cray T3E drawing about 300,000 watts in active mode (see Table 5-17).

Table 5-17: Supercomputer – Representative System Power Draw

Power Draw		
Type	**Power Draw, kW**	**Source**
Cray T3E	300	Tennessen (2001)
Cray T-90	175	Tennessen (2001)

Tennessen (2001) concurred with our estimate that supercomputers operate in “active” mode around the clock, to make full use of their computational power. Due to their remarkable power draw, the supercomputer AEC, 0.36 TW-h, equals that of the entire “high-end” server class (see Table 5-18).

Table 5-18: Supercomputer AEC Calculation

Type	Usage, h/year[41]	UEC, kWh/year	Total Stock	AEC, TW-h
Supercomputer System	8,760	1,746,659[42]	205	**0.36**

5.2.6 Data I/O Device Energy Consumption

Additional peripherals, primarily data I/O devices, play a key role in the functioning of server computers, particularly in high-end machines. This section quantifies their energy consumption impact. There are two types of data storage: optical and disk systems. Optical storage is used for archiving data and thus involves only the writing of data to the optical storage discs. Disk storage typically interacts (reading and writing data) more frequently with outside systems and must be constantly accessible. The following sub-sections address the two storage types separately.

5.2.6.1 Optical and Tape Storage Systems

Table 5-19 displays optical and tape storage unit installed base estimates for the Y2000, from Amatruda and Brown (2000).

Table 5-19: Optical/Tape Storage System Stock in the Year 2000 (from Amatruda and Brown, 2000)

Tape Storage	Stock (thousands)
Entry-level	4,892
Low-end	5,463
Midrange	1,832
High level	273

Optical and tape storage drives draw most of their power when in the "active" mode (i.e., while reading or writing data). We estimated power draw for these drives only for the active state, using values from manufacturers shown in Table 5-20.

[41] Tennesen (2001), Cray – personal communication

[42] Based on 40 units being Cray T-3Es and the remainder being T-90s.

Table 5-20: Optical/Tape Drive Power Draw Estimates

Drive Class	Active Power, Watts
Entry Level[43]	10
Low Range[44]	23
Midrange[45]	100
Enterprise[46]	700

The active mode duration estimates in Table 5-21 reflect ADL's estimate of the time needed to archive data on the server drives, which typically occurs every night, as well as infrequent non-standard data access occasions.

Table 5-21: Optical/Tape Drive Usage Time in Active Mode (ADL Estimates)

Drive Class	Active, hours
Entry-Level	2
Low-Range	2
Midrange	3
Enterprise	8

Table 5-22 presents optical/tape drives AECs, broken down by category.

Table 5-22: Optical/Tape Drive AEC

Server Numbers	Energy Consumption (GW-h)
Entry-level	36
Low-Range	92
Midrange	201
Enterprise	557
TOTAL (TW-h)	0.9TW-h

5.2.6.2 Magnetic Disk Storage Systems

Sheppard and Gray (2000) provide information about disk drive or general system storage shipments (for servers) over our estimated three-year lifetime (see Table 5-23).

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[43] http://www.products.storage.hp.com/eprise/main/storage/DisplayPages/specifications.htm?DataPage=dds2-dat8

[44] OnStream SCSI, from web-site, this is an actual power draw

[45] http://www.adic.com/US/English/Products/Hardware/LTO/FastStorLTO/index.html#specifications

[46] http://www.storagetek.com/products/tape/4490/4490_sp.htm

Table 5-23: Magnetic Disk Storage System Shipments (from Sheppard and Gray, 2000)

Year	Shipment, Terabytes
1997	24,405
1998	46,794
1999	87,209

Unfortunately, disk storage system shipment data or estimates for Y2000 were not available and, as such, 1997-1999 shipment data were used to develop energy consumption estimates. We will revisit the possible impact of this data hole at the end of the AEC analysis.

According to Moore (2001), magnetic disk storage density increased at "60 percent or more year through the 1990s." Consequently, capacity per device has increased over the last three years at a similar rate while power draw per device has remained approximately constant. Magnetic storage involves the "writing" of data onto a disc with discrete storage elements for each bit of data. As the disc rotates, a head reads or writes data from or to the disc, and spinning the discs accounts for most of the energy consumed by disc storage systems. Historically, data storage has increased primarily by increasing the density of the data written upon the discs while maintaining the same disc size. Thus, the amount of disc rotated does not change appreciably and the power draw per byte of storage decreases rapidly.

To calculate total disc storage energy consumption, we retrieved information on power draw for equipment typically installed in each of the three years (see Table C-1 in Appendix C). Table 5-24 illustrates that power consumption per byte of memory decreased rapidly from 1997 to 1999.

Table 5-24: Magnetic Disk System Ratio of Power Draw to Memory

Year	Power Draw, (W/TB)
1997	1014
1998	522
1999	307

The magnetic drive AEC calculation in Table 5-25 incorporates the stock and power draw values outlined above and an 8,760 hours/year running time[47].

[47] To enable prompt data I/O, disc drive systems rarely "spin down" into a lower power mode.

Table 5-25: Magnetic Disk Drive AEC[48]

Equipment Year	Power Draw, (W/TB)	Disk Drive Shipments (Terabytes)	Energy Consumption, (GW-h)
1997	1,014	24,405	217
1998	522	46,794	214
1999	307	87,209	234
TOTAL Energy Consumption (TW-h)			0.67

Magnetic disk drive AEC, broken down by vintage, proved to be remarkably consistent over the period 1997-1999. We expect that the same trends continued into Y2000 (i.e., large increases in terabytes shipped and similar decreases in power draw per terabyte). This directly implies that the substitution of Y2000 shipments for Y1997 shipments would have a small impact on the magnetic drive AEC estimate.

5.2.7 Server and Data I/O Device Energy Consumption

As noted in the discussion of server computers, server computers work in conjunction with data I/O devices, often reading and writing information to and from each other. It was not possible to allocate the data I/O device AEC between the different server computers. Instead, we decided to add the data I/O AECs to the server AECs to develop an estimate of the total AEC of server systems. Table 5-26 shows that server systems consume more energy in a year than all devices except PCs and monitors.

Table 5-26: Total Server System Energy Consumption

Server System Component	Year 2000 Energy Consumption, TW-h
Low, <$24.9K	4.5
Workhorse, $25-99.9K	3.3
Mid-range, $100-999K	2.0
High-end, $1,000K+	0.4
Optical/Tape Drive	0.9
Magnetic Disk Drive	0.7
TOTAL AEC Server Computers and Data Storage Systems, TW-h	11.6

[48] Equipment shipped through 1999; not including any equipment shipped in 2000.

5.3 Monitors and Display Terminals

5.3.1 Background

Monitors and display terminals are actually distinct entities. A display merely presents a visual image seen by the user, while a monitor includes the display and the circuitry that converts an electrical signal from the computer to the monitor into a visual image.

Conventional monitors resemble and are very similar to televisions, but without an antenna or the components needed to receive a broadcasting signal. Both use a cathode ray tube (CRT) to convert electrical signals to the visual display seen on the screen. CRTs project electrons onto a screen by using an electron gun to emit electrons. Anodes accelerate the electrons, which are then “steered” by a varying electromagnetic field onto different parts of the screen, where they interact with a coating of phosphor compounds that convert the electron signal into a visual signal. In essence, the CRT “paints” an image on the phosphor layer. In contrast to monochrome displays, which use a single electron gun, color monitors use three different electron guns (red, blue, and green) to create color images.

Laptop and portable computers also have displays but they are not CRT-based. Instead, they use liquid crystal displays, or LCDs. LCDs consume a fraction of the energy and space of CRTs, making them the solution for portable (and battery-powered) devices. Driven by a desire to conserve space in some applications where space is limited (e.g., a stock broker’s desk), flat screen monitors have recently entered the market. LCD sales volumes remain low relative to CRTs due to a substantial cost premium: circa July 2001, a 17-inch LCD monitor cost is ~$1,000, or three to four times the cost of a 17-inch CRT monitor (PC Connection, 2001). LCDs also often appear as control display panels or displays for copiers, facsimile machines, telephones, and handheld computers, sometimes incorporating interactive capabilities (i.e., the user can touch the screen to control the device).

Instead of projecting light onto a screen, LCDs reflects useable light, typically in conjunction with additional light sources to “back light” the screen. Nematic[49] LCDs are the most common type of LCD in the market and can be either passive or active matrix. The main advantage of an active matrix screen is that it performs more similarly to CRTs (e.g., higher image quality when viewed at an angle), without their disadvantage of weight, size, and high energy consumption. The disadvantage of active matrix is its higher cost.[50]

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[49]Nematic refers to the molecule type of the liquid used in the display.

[50] http://204.56.132.222/courses/CIS312J/EBOOK/wrh17.htm#E70E549 and http://www.glencoe.com/norton/n-instructor-/updates/1999/51099-3.html

Looking further out, organic light-emitting diode (OLED) displays have the potential to displace LCDs. They use light-emitting diodes sandwiched between an anode and the screen cathode to generate clearer displays than LCD technology, to the point where Sony intends to sell 20- to 30-inch OLED TV screens by 2003 (Economist, 2001b). Johnstone (2001) notes that their simplified design, which eliminates the energy-consuming back-lighting used by LCDs, makes them more compact and lighter than LCDs and, ultimately when produced in volume, as much as 50% less expensive than LCDs (Economist, 2001b). From an energy perspective, OLEDs could (but do not at present; Semenza, 2001b) consume about 1/3rd the power of LCDs, making them ideal for portable devices such as laptop computers, smart handheld devices, wireless phones, etc. Difficulties with sustaining color over time currently hamper deployment of OLEDs in high-usage products, but over 90 companies continue to work on this technology (Johnstone, 2001), a clear indication of its ultimate potential.

Cholesteric LCDs[51], initially developed at Kent State University, are one of several "bi-stable" display technologies. As their name implies, bi-stable displays incorporate an array of discrete blocks of material, each of which has two stable states (e.g., black or white). An electric field or other mechanism switches the discrete materials between states only when that portion of the image changes, potentially leading to 10-fold or greater reductions in energy consumption. Color displays simply use three stacked layers that reflect red, blue, and green. In spite of their promise, cost and display speed issues remain. At present, cholesteric displays are extremely expensive, with a six-inch display costing $300 in production (Economist Technology Quarterly, 2000A). Slow addressing speeds (i.e., the rate at which the displayed image can change) also plague cholesteric LCDs, making them currently unsuitable for displaying video content on monitors (Semenza, 2001b). These two barriers will impede commercialization of cholesteric LCDs in office equipment for several years to come (Semenza, 2001b).

As flat screen technologies mature and their costs decrease, they will take a greater share of the market from CRTs because of their superior aesthetics, increased image clarity (Semenza, 2001b) and decreased spatial footprint. This transition has significant energy implications: a LCD uses about 70% less energy than a comparable CRT[52]. Other display technologies competing with LCD include field emission, electro-luminescent, and gas-plasma displays. To date, none of these technologies has proven superior to the liquid crystal display.

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[51] The liquid crystal material is made from cholesterol.

[52] See http://www.glencoe.com/norton/n-instructor-/updates/1999/51099-3.html

5.3.2 Monitor and Display Terminal Stock

The literature review located three sources for monitor shipment data. The first, the ITIC Databook (2000) assumed one monitor per shipment of computer, regardless of computer size. As shown in Table 5-27, ITIC (2000) also included general display terminal shipment data.

Table 5-27: Monitor and General Display Unit Shipment Data (from ITIC, 2000)

Year	Monitors (thousands)	General Displays (thousands)
1996	26,853	3,300
1997	32,073	3,310
1998	36,976	3,200
1999	44,568	3,250
2000	49,241	3,120

Semenza[53] (2001a) also provided CRT and LCD shipment data for monitors over the 1996-2000 (see Tables 5-28 and 5-29).

Table 5-28: CRT Monitor Shipments (from Semenza, 2001a)

Year	Shipments (thousands)					
	<=14-inch	15-inch	17-inch	19-inch	>=20-inch	Total
1996	9,528	9,185	5,687	N/A	1,091	25,491
1997	6,729	13,039	9,359	182	1,425	30,734
1998	4,167	14,098	14,954	1,663	1,631	36,513
1999	2,546	15,401	18,508	3,486	1,810	41,751
2000	1,813	8,667	27,087	6,036	2,331	45,934

Table 5-29: LCD Monitor Shipments (from Semenza, 2001a)

Year	Shipments (thousands)				
	<=13-inch	14-inch	15-inch	>=16-inch	Total
1996	28	1	N/A	N/A	29
1997	12	8	4	10	34
1998	17	71	122	29	239
1999	6	72	546	112	736
2000	11	45	1,512	326	1,894

[53] P. Semenza of Stanford Resources-iSuppli indicated that the values published in an electronic product recycling study sponsored by the National Safety Council (1999) were incorrect; the ones published here are the correct values.

In addition, the International Data Corporation published a report containing shipment data from 1999-2004 broken-down by monitor type and size (IDC, 2000). Table 5-30 reports key data, including our "back-cast" [54] 1997 and 1998 shipment estimates from actual shipment data of 1999 and 2000 and projections through 2004.

Table 5-30: Monitor Shipment Data, by Type and Size, based upon IDC (2000)

Monitor Technology and Size	Number of Units shipped (thousands)			
CRT	1997*	1998*	1999	2000
14in.	*3,300*	*2,700*	2,121	1,602
15in.	*17,500*	*15,000*	12,678	11,294
17in.	*11,500*	*13,500*	16,075	18,255
19in.	*1,600*	*2,150*	2,699	3,810
20/21in.	*550*	*950*	1,367	1,901
21 in. +	-	-	-	4
LCD				
< 14 in.			14	2
14in.			194	127
15in.			341	930
17in.			12	70
18in.			20	47
20in.			2	9
20 in. +			-	3

* Numbers in *italics* represent "back-cast" estimates

In general, the total shipment values of the three monitor shipment sources do not differ greatly. Assuming that each commercial desktop PC and workstation has one monitor[55] yields a total of 61.1 million monitors, and apply the IDC (2000) breakdown of monitor shipments by monitor size and type over a four-year equipment lifetime[56] (EPR, 1999). The general display stock estimate comes from the ITIC (1999) data, also summed over a four-year period. Figure 5-2 summarizes the monitor and display stock estimates.

[54] We developed the back-cast values via a linear least-squares fit of the Y1999-Y2004 data and projections.

[55] This assumption may slightly under-estimate monitor stocks, as some PCs (both laptop and desktop) use additional monitors; however, we expect this error to be small, on the order of several percent.

[56] Kawamoto et al. (2001) also used a four-year lifetime, based upon IRS equipment depreciation guidelines.

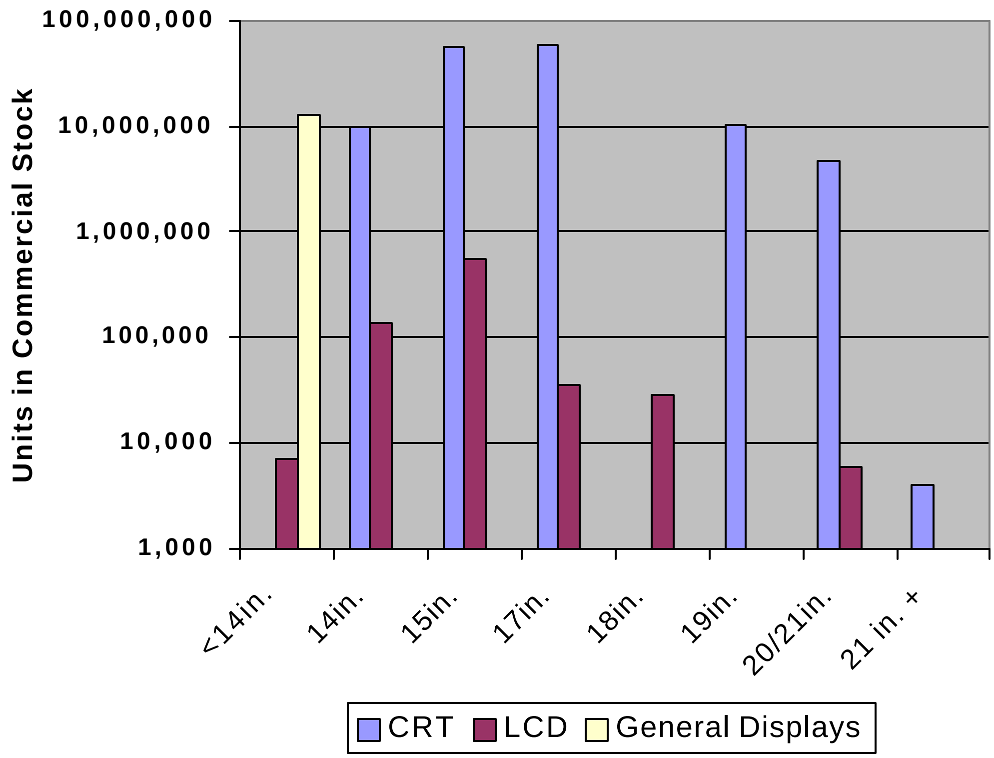

Figure 5-2: Monitor and General Display Stock Estimates, by Technology and Size

5.3.3 AEC Calculation

Several sources exist for data on measured power draw by operation mode for CRT monitors (Table 5-31) and they categorize monitor power consumption differently. MACEBUR (1998) offers five distinct power consumption modes, Meyer and Schaltegger (1999) four, and Kawamoto et al. (2001) three primary modes of operation. MACEBUR (1998) and Meyer and Schaltegger (1999) both categorize power draw in the same manner: active equates to on and in use; standby – screensaver mode; suspend – screen powers down; off – power switch is turned off; and unplugged – disconnected from the electrical socket. On the other hand, Kawamoto et al. define the modes as follows: active – on; low – screen powered down (i.e., no screen saver); and off – monitor switched off.

Table 5-31: CRT Monitor Power Consumption Sources

	CRT Power Draw in Operational Mode, Watts					
Type	**Active**	**Standby**	**Suspend**	**Off**	**Unplugged**	**Source**
14-15"	61	53	19	3	0	MACEBUR (1998)
17-21"	96	86	16	5	0	MACEBUR (1998)
17"	90	26	9.2	4.3	N/A	Meyer and Schaltegger (1999)
19"	104	31	13	4	N/A	Meyer and Schaltegger (1999)
21"	135	43	14	4.7	N/A	Meyer and Schaltegger (1999)
Monitor (Average, Commercial and Industrial)	85	N/A	5	0.5	N/A	Kawamoto et al. (2001)
Display Terminal (Average, Commercial and Industrial)	75	N/A	5	0.5	N/A	Kawamoto et al. (2001)

None of the three studies addressed LCD power draw. Instead, the LCD power draw values displayed in Table 5-32 came from obtaining LCD nameplate power draw from manufacturers and estimating the active power draw from an approximate ratio of nameplate-to-active power draw. Hosni et al. (1999) found that nameplate values overstate the "active-mode" power draw of monitors by a factor of *3 or more*. To be conservative, we applied a nameplate-to-actual power draw ratio for CRTs of 33%. Similarly, we developed approximate power draw values for other modes by extrapolating the active-to-other mode power ratios for CRTs reported by Meyer and Schaltegger (1999). A comparison with laptop LCD energy consumption levels (e.g., the Compaq Armada E500 15.0- and 14.1-inch displays draw 4.2 and 5.2W, respectively[57]) suggests that these levels may be somewhat high.

[57] See product information at: www.compaq.com .

Table 5-32: LCD Power Consumption Data

	LCD Power Draw by Operational Mode, Watts				
Viewing Size (in.)	Nameplate[58]	Active[59]	Standby[60]	Suspend[61]	Off
13	7.5	*2.5*	*0.7*	*0.2*	*0.1*
14	20	*6.7*	*1.9*	*0.7*	*0.3*
15	35	*11.7*	*3.4*	*1.2*	*0.6*
17	50	*16.7*	*4.8*	*1.7*	*0.8*
18	75	*25.0*	*7.2*	*2.5*	*1.2*
20	95	*31.7*	*9.2*	*3.2*	*1.6*
21	107	*36*	*10.4*	*3.6*	*1.8*
Note: *Italics* denote estimated values.					

Table 5-33 lists the power draw values used to calculate the total energy consumption of CRTs, LCDs, and general displays, leveraging the measurements of different monitor sizes made in different studies.

Table 5-33: Power Draw Values Used for AEC Calculations, by Monitor Size and Type

	Power Draw by Mode and Monitor Size, Watts			
Monitor Size	Active	Suspend	Off	Source
CRT Monitors				
15in.	61	19	3	MACEBUR (1998)
17in.	90	9	4	Meyer and Schaltegger (1999)
19in.	104	13	4	Meyer and Schaltegger (1999)
20/21in.	135	14	5	Meyer and Schaltegger (1999)
21 in. +	135	14	5	Meyer and Schaltegger (1999)
LCD Monitors (from Table 5-32)				
< 14 in.	2.5	0.7	0.1	
14in.	6.7	1.9	0.3	
15in.	11.7	3.4	0.6	
17in.	16.7	4.8	0.8	
18in.	25.0	7.2	1.2	
20in.	31.7	9.2	1.6	
20 in. +	35.8	10.4	1.8	

Each data source of measured power draw for CRTs also had data for usage patterns (see Table 5-34).

[58] See www.computerprerference.com .

[59] Estimated using 33% "active"-to-nameplate power ratio.

[60] Estimates based upon Meyer and Schaltegger (1999) "active"-to-"standby" power ratio for CRT data.

[61] Estimates based upon Meyer and Schaltegger (1999) "standby"-to-"suspend" power ratio for CRT data.

Table 5-34: Monitor Usage Pattern Data by Operational Mode

Time in Operational Mode, hours/year					
Size	**On**	**Standby**	**Suspend**	**Off**	**Source**
14-15"	614	789	614	2,279	MACEBUR, (1998)
17-21"	1,403	1,666	175	1,490	MACEBUR, (1998)
17" w/Power Management (PM)	783	391	1,304	6,288	Meyer and Schaltegger (1999)
19" w/PM	783	391	1,304	6,288	Meyer and Schaltegger (1999)
21" w/PM	783	391	1,304	6,288	Meyer and Schaltegger (1999)
17" no PM	2,478	0	0	6,288	Meyer and Schaltegger (1999)
19" no PM	2,478	0	0	6,288	Meyer and Schaltegger (1999)
21" no PM	2,478	0	0	6,288	Meyer and Schaltegger (1999)
17"	2,278	N/A	1,915	4,568	Kawamoto et al. (2001)
All Monitors and General Displays	**3,281**	**N/A**	**2,980**	**2,505**	**Current Study**

Tables G-1 through G-5 provide details of the usage calculations (see Appendix G) used for the current study.

Table 5-35 summarizes the overall AEC calculation for monitors and general displays. The general display unit-energy-consumption uses the MACEBUR (1998) 14-15 inch monitor power draw (Table 5-33) and CRT usage information (Table 5-34).

Table 5-35: Monitor and General Display AEC

Monitor/Display Size (inches)	**CRT Commercial Stock**	**LCD Monitor Commercial Stock**	**CRT AEC, (TW-h)**	**LCD AEC, (TW-h)**	**General Display AEC, (TW-h)**
<14-inch		16,000		0.0001	
14-inch	4,226,264	321,000	1.1	0.004	
15-inch	24,546,496	1,271,000	6.5	0.030	
17-inch	25,788,773	82,000	8.5	0.003	
18-inch		67,000		0.003	
19-inch	4,459,245		1.7		
20-inch		11,000		0.0006	
20+-inch		3,000		0.0002	
20/21-inch	2,072,491		1.0		
21+-inch	1,739		0.0009		
Total	61,095,008	1,771,000	**18.7**	**0.04**	**3.4**
AEC, Monitors and General Displays (TW-h)				**22.2**	

A large uncertainty exists for general display AEC because the calculation applied monitor usage patterns in lieu of (non-existent) general display usage data. Implicit in that assumption is that general displays have the same ENERGY STAR®-enabled rate as monitors and that monitors have the same day length as monitors (i.e., 48 hours). ENERGY STAR® general displays do exist (Nordman, 2001), but their market penetration and enabled rate are unknown and could be lower. More importantly, general displays often are associated with systems that operate for extended hours (e.g., mainframe computers, in airports). Thus, actual general display usage in "active" mode may be significantly higher than the current estimate, which would result in a substantially greater display terminal AEC.

5.4 Copy Machines (Copiers)

5.4.1 Background

Chester F. Carlson pioneered modern copier technology when he applied for his first patent of electro-photography, or Xerography, in 1937. In 1947, he completed a contract with the Haloid Company in Rochester, NY, ultimately re-named the Xerox Corporation. Early copy machines came to market in 1949 and proved to be very cumbersome. Ten years later, in 1959, Xerox introduced the first desktop copy machine, the Model 914. Over the following decades, the copy-machine became a mainstay in the office world and several other companies have joined Xerox as major players in the market, including Canon, Panasonic, and Toshiba.

Copiers have advanced substantially since the advent of the Model 914 copier, notably increases in copying rate, quality improvements, and the introduction of color copiers. For instance, some machines copy at rates approaching 150 cpm (copies per minute), can sort paper, staple, remove staples, copy in color, bind small books, and do many of these tasks automatically. Nonetheless, the copying process has not changed appreciably. The laser printer discussion in Section 5.5 explains the basic process of how the machine transfers toner to paper via electrostatic charge patterns established by high-intensity light.

Analog copiers and laser printers do differ in the method that they assemble input data. Laser printers accept document files from a computer and send an electronic signal to a laser, whose light places and cures toner onto the page. In contrast, analog copy machines use a light source and mirrors to reflect the darker and lighter sections of the original on to a hot toner drum that subsequently transfers the toner to paper sheets.

Digital copy machines began to play a significant role in the copier market circa 1997. A digital machine uses a digital scanner to capture the image and then electronically charges portion of the drum, using a laser. Digital copiers offer three advantages over analog copiers. First, digital systems are more robust: analog copiers' mirrors can come out of alignment, requiring maintenance whereas digital copiers do not include mirrors, thereby decreasing maintenance expenses. Second, digital copiers achieve higher ppm (page-per-minute) rates. Third, they consume slightly less energy because, in cases where the copier generates multiple copies of a page or document, digital copiers require but a single light burst as opposed to needing a bright light supply for each copy. That is, digital copiers only need to scan the image once and then re-use the initial signal for repeat images. Currently, digital new product sales make up about 70% of total sales and will likely approach 100% in the future.[62]

Digital copy machines potentially offer additional value in office environments because they can (but usually do not) fulfill the role currently played by several discrete devices, including copiers, scanners, facsimile machines, and printers. Ultimately, multi-function "copiers" could become integral parts of computer networks, as illustrated in Figure 5-3. Outside of the traditional office environment, high-quality, high-speed copy machines integrated into computer networks could transform the publishing business by enabling print-on-demand books.

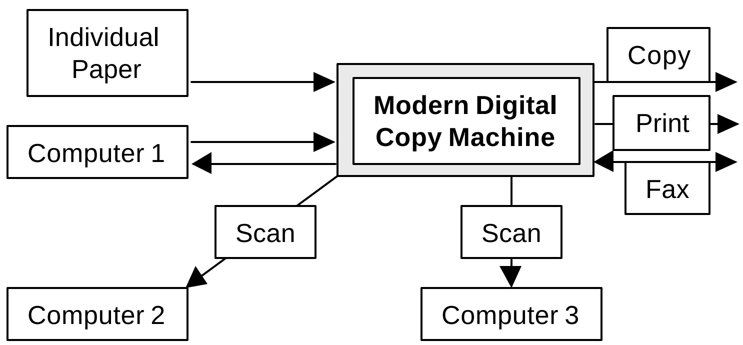

Figure 5-3: Range of Capabilities of a State-of-the-Art Digital Copy Machine

Copy machines have high unit energy consumption, primarily due to very high power draws during copying and high stand-by power levels to maintain fuser rolls in a hot, ready state. Re-heating a cooled fuser roll can take several minutes, which often poses an unacceptably long delay in the fast-paced office environment and dictates substantial time periods[63] before powering-down the copier into sleep mode. Advances in copier fuser systems, including toner materials with lower melting temperatures, can result in substantial decreases in copier energy consumption in "active" and "stand-by" modes by decreasing the fusing temperature and the amount of energy needed to keep the fuser rolls hot. Furthermore, lower fusing temperatures would also decrease the warm-up time, perhaps to only a few

[62] From conversation with a Xerox representative.

[63] According to EPA (1999), Energy Star-compliant copiers with rates >40cpm must enter "suspend" mode after 15 minutes or less of inactivity, while slower machines do not have an "suspend" mode requirement. Similarly, Energy Star copiers must enter "auto-off" mode after less than between 30 and 90 minutes of inactivity, depending upon machine capacity (2001). The program mandates a 30-second recovery time from "suspend" for some lower-speed (<40cpm) copiers and suggests the same recovery time for higher capacity copiers.

seconds (Loutfy, 2001), enabling copiers to spend more time in the low-power "sleep" mode.

5.4.2 Copy Machine Stock

Kmetz (2000) reports copy machine shipment data and projections by copier speed; Table 5-36 presents Kmetz's data, including back-cast shipments for 1995-1997 developed by ADL[64].

Table 5-36: Analog and Digital Copier Shipment Data, by Band – in Thousands of Units[65]; Back-cast Values in *italics* (Data from Kmetz, 2000, Projections by ADL)

	Retail Band	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Year	**Retail 1-16 cpm**	**17-20 cpm**	**21-30 cpm**	**31-44 cpm**	**45-69 cpm**	**70-90 cpm**	**91+ cpm**
1995	*660*	*441*	*960*	*65*	*190*	*72*	*27*
1996	*675*	*445*	*750*	*101*	*207*	*60*	*22*
1997	*685*	*448*	*580*	*140*	*220*	*46*	*17*
1998	704	450	485	148	236	40	14
1999	719	458	245	222	246	23	10
2000	730	460	220	265	260	22	9

We calculated the copier installed base based on the above copier sales data over an equipment lifetime of six years, (from Kawamoto et al., 2001, who used IRS depreciation values). RECS (1997) estimated that 3.8 million households circa 1997 had a copy machine; presumably, most of these came from the "Retail Band" (1-16cpm). Table 5-37 shows that unit sales of copiers in the "Retail Band" have increased about 10% over the last six years, suggesting that the stock of copiers in residences over that period has not changed appreciably over that period. Thus, the commercial copier stock by band came from subtracting the RECS residential stock estimate from the retail band of copy machines (see Table 5-37).

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[64] Kmetz (2000) published shipments from 1998 projected through 2004. We used these trends to back-cast shipment data to 1995 based upon a least-squares linear curve fit.

[65] Data from Kmetz (2000), back-cast Values in *italics,* performed by ADL.

Table 5-37: Year 2000 Copy Machine Installed Base, by Band – in Thousands of Units

Band	Retail Band	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Copy Rate	retail 1-16 cpm	17-20 cpm	21-30 cpm	31-44 cpm	45-69 cpm	70-90 cpm	91+ cpm
Total Stock	4,173	2,701	3,240	942	1,359	263	98
Commercial Stock	373	2,701	3,240	942	1,359	263	98

5.4.3 Copier AEC Calculations

Table 5-38 presents copier power draw data and data references.

Table 5-38: Copy Machine Power Draw from Various Sources, in Watts

Type	Active	Standby	Suspend	Off	Source
Desktop - Wilkins	400	85	20	0	Wilkins and Hosni (2000)
Office- Wilkins	1,100	400	300	0	Wilkins and Hosni (2000)
<12 cpm	778	56	2.2	1.1	Meyer and Schaltegger (1999)
12-30 cpm	1,044	179	42	0.5	Meyer and Schaltegger (1999)
31-69 cpm	1,354	396	68	0.6	Meyer and Schaltegger (1999)
70+ cpm	2,963	673	300	2.3	Meyer and Schaltegger (1999)
Average of 37 copiers	660	74	5	0	MACEBUR (1998)
Band 1 and Retail	136	115	–	8	Nordman et al. (1998)
Band 2	208	172	106	13	Nordman et al. (1998)
Band 3	241	183	70	16	Nordman et al. (1998)
Band 4	358	266	97	39	Nordman et al. (1998)
Band 5	583	358	98	20	Nordman et al. (1998)
Band 6	1,044	622	221	21	Nordman et al. (1998)

The power draw values reported by Nordman et al. (1998) differ dramatically from the measurements of Meyer and Schaltegger (1999) because they do not represent actual power draw measurement during operation in a given mode. Instead, they are measurements for machines using the 1994 ASTM test procedure for an *operating pattern* identified for each mode. Because the ASTM data do not provide much insight into the power draw by operating mode, we selected the Meyer and Schaltegger (1999) values from Table 5-38 for our copier energy consumption model.

Usage data corresponding to each mode is available from Meyer and Schaltegger (1999), MACEBUR (1998), and Kawamoto et al. (2001). However, as discussed in detail in Appendix D, Kawamoto et al. (2001) apply a different methodology, foregoing an "active" (imaging) mode and accounting for printing power via an addition of 1W-h per photocopied image. We adopted this methodology for the same reason that Kawamoto et al. did – to avoid large uncertainties in the actual amount of time spent in the "active" mode. Table 5-39 shows the usage time by mode for each study, including the current study.

Table 5-39: Copy Machine Usage, Various Sources, Hours/Year

Type	Active	Standby	Suspend	Off	Source
<12 cpm	21	1,543	521	6,674	Meyer and Schaltegger (1999)
12-30 cpm	227	1,442	1,460	5,631	Meyer and Schaltegger (1999)
31-69 cpm	313	1,408	1,408	5,631	Meyer and Schaltegger (1999)
70+ cpm	501	1,314	1,314	5,631	Meyer and Schaltegger (1999)
Average of 37 copiers	701	2,365	3,329	2,365	MACEBUR (1998)
Weighted Average, Multiple Copier Speeds	N/A	3,310	2,482	2,967	Kawamoto et al. (2001)
All Copier Bands	**N/A**	**3,281**	**2,980**	**2,505**	**Current Study**

Tables G-1 through G-5 provide details of the usage calculations used for the current study (see Appendix G).

Table 5-40 presents the copy machine AEC, calculated using the stocks and power draws for each copier class, excluding energy consumed while producing images.

Table 5-40: Copy Machine AEC, Excluding Copying Energy

Copier Class	AEC, TW-h
Retail Band, 1 – 16 cpm	0.29
Band 1, 17-20 cpm	2.1[66]
Band 2, 21-30 cpm	3.3
Band 3, 31-44 cpm	0.95
Band 4, 45-69 cpm	2.0
Band 5, 70-90 cpm	0.49
Band 6, 91+ cpm	0.33
TOTAL AEC, TW-h	9.5

Table 5-41 summarizes the estimate of the total number of images copied and the energy consumed by image copying (see Appendix D for more detail).

[66] The Energy Star homepage (www.energystar.gov) indicates that Energy Star-compliant copiers in the 20cpm< range need not have a "sleep" mode; instead, they must enter an "off" mode, consuming <5W, after no more than 30 minutes of operation. If this "off" mode power draw supplants the "low" power draw, the 1-20cpm band AEC would decrease by ~0.5TW-h.

Table 5-41: Copier Image Production and Energy Consumption Estimates

Copier Type	Duplex Rate, Kawamoto et al. (2001)	Total Images by Band (millions)	Copying Energy by Band (GW-h)
Band 1 – retail	0%	67	0.07
Band 1	2%	12,000	12
Band 2	8%	41,000	41
Band 3	14%	21,000	21
Band 4	32% [67]	45,000	45
Band 5	40%	31,000	31
Band 6	60%	46,000	46
		TOTAL Energy Consumption, GW-h	197

Table 5-42 presents the AEC for copiers and reveals that keeping copiers ready to copy (versus actually making copies) consumes the vast majority (more than 95%) of all energy consumed by copiers. It is consistent with the fact that most copy machines make copies for only a very small fraction of the 8,760 hours in a year.

Table 5-42: Total Copy Machine Annual electricity consumption, Year 2000, TW-h

Standby, Suspend, and Off AEC, TW-h	Active (Copying) AEC, TW-h	Copy Machine TOTAL AEC, TW-h
9.5	0.2	9.7

5.5 Printers

5.5.1 Background

Printing is an integral part of business communication, including but certainly not limited to, generating reports and memoranda, producing engineering drawings, and creating graphics. Three printer types, laser, inkjet, and impact, constitute almost the entirety of the printer market. Typically, laser printers are shared resources between several users in a computer network, whereas inkjet printers may serve as personal printers or the sole printers in smaller businesses. Impact printers are generally used in the back office as part of order fulfillment systems, printing information onto multiple copies of forms via carbon copies (e.g., in warehouses).

[67] An updated duplex rate from Nordman et al. (1998).

Inkjet and laser printers predominate in standard office applications. The first inkjet printer was invented in 1976, while Xerox developed the first laser printer in 1978[68] and laser printers came into widespread commercial use in the early 1980's. Hewlett-Packard has long dominated the laser printer market. At present, laser printers have a very large portion of the mainstream commercial printing market due to their higher speed (measured in pages per minute, or ppm), superior image clarity, and lower cost per printed page. In contrast, inkjet printers offer lower first cost and offer affordable color printing, while consuming less energy than laser printers. Refinements and cost reduction of both inkjet and laser technologies have led to the decline of impact printers in the market.

Laser printing is very similar to the xerographic process, differing in how the input data are gathered and used. Laser printing interprets electronic signals representing an image (page) sent to the printer, whereas analog xerography manipulates the reflected light from the copied paper. During operation, a laser printer receives an electronic signal from the computer that triggers a laser. The laser then shines upon on certain areas of a rotating drum, creates a charge pattern that defines the image or text to be printed. Next, the charged portion of the drum rotates past the toner supply, attracting particles of toner to the charged areas of the drum. As the drum continues to rotate over the paper, a charged wire beneath the paper draws the toner from the drum and onto the paper. Finally, the page the paper travels into the fuser, where a pair of hot rollers fuse the toner to the paper and then eject the paper from the printer[69], a process known as electrostatic printing. Laser printers consume much more energy than inkjet printers primarily because the fuser rolls must remain at high temperatures to bond the toner to the paper. During printing, the laser printer actively supplies resistance heat to ensure effective bonding; in addition, laser printers in stand-by mode require perpetual heating to avoid heat-up driven delays in response to a print request.

In contrast, inkjet printers produce images by precisely moving an ink-containing cartridge with an array of orifices (which create the eponymous "inkjets") across each sheet of paper. The cartridge ejects a very high frequency stream of tiny dots from each orifice of wet ink on the paper from a cartridge containing one or more colors of ink. Inkjets produce ink droplets either by rapidly-deforming piezoelectric elements which release droplets from an ink pressure chamber (Yoshimura et al., 1998), or by very rapid bursts of heat which locally expand and expel the ink from the cartridge. The inkjet printer does not have fuser rolls or other components that would draw large amounts of power.

Impact printers include dot-matrix printers and daisy-wheel printers. As their name implies, they create patterns on paper by actually striking the page through a ribbon,

[68] http://inventors.about.com/science/inventors/library/inventors/blcomputer_printers.htm

[69] http://www.netten.com/~garycox/laser.htm

similar to a typewriter. This enables impact printers to generate multiple copies of forms (e.g., invoices) via carbon paper layers, and they continue to play a major role in back-offices. Used in this manner, their ppm rate can match or exceed those of the fastest laser printers. Impact printers have fallen out of favor in most other commercial applications due to inferior print quality, slow speed (when printing documents and images), inability to produce drawings, and higher noise levels (from the impacting pins or print head).

In the future, the number of color laser printers in the office could increase; however, this is only likely to occur if color laser printers become faster and their price continues to decrease. In that case, the inkjet market would be highly challenged to find another niche to fill. Another frontier in which electronic printing may gain market share is the short-run publishing business. Companies are creating machines capable of greater print finishing tasks and gull automation of finishing practices and the lower costs for short printing runs could become very competitive with the traditional offset technology.

5.5.2 Printer Stock

This study classified printers as laser, inkjet, impact, line[70], and other[71] printers. As summarized in Table 5-43, Frasco (1999) provides printer yearly shipment data and projections for the five printer types.

Table 5-43: Annual Printer Shipments, by Type and Class, in thousands (from Frasco, 1999)

Type	1997	1998	1999	*2000*[72]
Impact Printer: 9-pin	405	438	410	*382*
Impact Printer: 24-pin	382	349	317	*286*
Impact Printer: 18-pin	20	18	15	*13*
Line Matrix	22	22	21	*20*
Line character	1	0	0	*0*
Thermal Printer	25	16	12	*9*
Dye Sublimation	20	27	34	*38*
Inkjet	12,200	15,105	17,700	*19,600*
Laser, Small Desktop (<12 ppm)	2,531	1,531	1,850	*2,070*
Laser, Desktop (13-29 ppm)	548	1,275	1,670	*1,955*
Laser, Small Office (30-69 ppm)	8	36	73	*104*
Laser, Large Office (70+ ppm)	2	3	4	*5*
Laser, Color	85	129	209	*293*

[70] Includes line matrix and line character printers.

[71] "Other" printers include dye sublimation and thermal printers.

[72] Projected shipments for 2000.

The stock estimates reflect the four-year lifetime as reported in EPR (1999), combined with shipment projections from Frasco (1999) for line, impact, and "other" printers, and projected installed base estimates for inkjet and laser printers from Su (1999). Our calculation of the portion of printers residing in commercial buildings relied on a two-pronged approach. First, we assumed that all impact, line, laser printers >12ppm, and "other" printers reside in commercial buildings. Second, we found the commercial stock of laser (<12ppm) and inkjet printers by estimating the residential printer stock subtracting it from the total printer stock. CEA (2001) reports 51% of U.S. households in 2000 had computer printers in them, implying a residential printer stock of 53.6 million[73] inkjet and small desktop laser printers. To allocate the inkjet and small desktop laser printers between commercial and residential spaces, we that equal percentages of the total inkjet and small desktop laser printer stocks reside in residences and commercial buildings, i.e. 11.5% of the small desktop laser and inkjet printers reside in commercial buildings. Table 5-44 shows the commercial stock breakdown.

Table 5-44: Commercial Stock of Printers, by Type and Class

Type	Commercial Stock, Units
9-pin	1,635,200
24-pin	1,334,200
18-pin	66,000
Line Matrix	84,200
Line character	900
Thermal Printer	62,400
Dye Sublimation	118,700
Inkjet	6,034,563
Laser, Small Desktop (<12 ppm)	924,260
Laser, Desktop (13-29 ppm)	5,096,353
Laser, Small Office (30-69 ppm)	220,188
Laser, Large Office (70+ ppm)	12,658
Laser, Color	560,256

The following sections present printer energy consumption separately for impact, line, inkjet, laser, and "other" printers.

[73] Based upon 105 million households (NTIA, 2000), assuming one printer per household with a printer.

5.5.3 Impact Printers

Table 5-45 presents the “active” power draws of representative (best-selling) Epson[74] impact printers and each one’s “active” power draw, while Table 5-46 shows impact printer “standby” power draw data from Norford et al. (1989).

Table 5-45: “Active” Mode Power Draw of Representative Epson Impact Printers (from Epson product literature, 2001)

Model	Active Power Draw, W	Printer Format
FX-880	36	9-pin, Narrow
FX-980	46	9-pin, Narrow
LQ-570	33	24-pin, Narrow

Table 5-46: Stand-By Power Draw of Impact Printers (from Norford et al., 1989)

Impact Printer Brand & Model	Power Consumption, Watts
Epson RX-80	9.7
Epson MX-100	19.1
Imagewriter II #1	13
Imagewriter II #2	11.2
Okidata 83A	19.7
Okidata 92	18.3
IMB Proprinter	26.3
Average Standby Power Draw, Watts	16.8

Based upon these values, we assigned the average values of 36.5 and 16.8 watts as the power draw in the “active“ and “standby” modes, respectively. Analogous to inkjet printers, impact printers do not have a “sleep” mode, because of their low power draw in “standby” mode. Lastly, we assumed an “off” power draw of 1W.

Lacking detailed usage information for impact printers, we applied many of the inkjet printer usage patterns to impact printers (see Table 5-51 and Appendix G, Tables G-1 through G-5).

Table 5-47 presents a summary of the impact printer energy consumption calculation, including the average UEC and the total impact printer AEC.

[74] Products suggested by Sturcke (2001), information found at www.epson.com

Table 5-47: Impact Printer Energy Consumption Summary

	Active	Standby	Off
Usage, h/year	394	6,263	2,102
Power Draw, W	36.5	16.8	1
UEC per Device, kW-h/year			122
AEC, TW-h			0.37

5.5.4 Line Printers

A line printer is a device used primarily to print bills and records; they typically print on the same type of form repetitively, running constantly, 8,760 hours per year (Mam, 2001). According to Mam (2001), a typical line printer draws 171W in print mode. Due to their relatively high power draw and around-the-clock operation, the relatively small stock of line printers consumes about 0.13TW-h of energy per year (see Table 5-48).

Table 5-48: Line Printer Energy Consumption Summary

Variable	Value
Line Printer Stock	85,100 Units
Hours/Year in "Active" Mode	8,760 hours
Power Draw in "Active" Mode, W	171W
UEC, kW-h/year	1,499
AEC, TW-h/year	0.13

5.5.5 Inkjet Printers

Tables 5-49 and 5-50 summarize data sources for inkjet printer draw and usage information. The Kawamoto et al. (2001) "active/ready" mode is analogous to the "standby/low" values reported by the other sources.

Table 5-49: Inkjet Printer Power Draw (in Watts) by Mode

Active/Ready	Standby/Low	Suspend	Off	Source
32	10	N/A	2.8	Meyer & Schaltegger (1999)
53	13	6	0	MACEBUR (1998)
17	N/A	N/A	2.0[75]	Kawamoto et al. (2001)

[75] Kawamoto et al. (2001) cite Meyer and Schaltegger (1999) as the source for their value, but use 2.0W instead of the 2.8W reported.

Table 5-50: Inkjet Printer Usage Time by Mode

Active	Standby	Suspend	Off	Source
52	2,034	0	6,674	Meyer & Schaltegger (1999)
175	1,840	4,205	2,540	MACEBUR (1998)
N/A	3,723	N/A	5,037	Kawamoto et al. (2001)

The usage mode data reveal two different methods to categorize energy consumption. The first, used in the Meyer & Schaltegger (1999) and similarly in MACEBUR (1998), sums energy consumption over all three/four possible modes of operation. The second, used by Kawamoto et al. (2001) considers only two modes of operation, "off" and "active" states. Kawamoto et al. (2001) account for "active" power draw by adding an additional 1W-h of energy for each image created by inkjet printers (e.g., from Su, 1999) to the modal energy consumption to calculate the total energy consumption. We did not apply the energy/image methodology to inkjet printers because the 1W-h/sheet energy consumption comes from studies of electrostatic reproduction energy consumption (e.g., Nordman, 1998), which is germane to copiers and laser printers but not the inkjet printing process.

Instead, we applied the three-mode methodology of Meyer and Schaltegger (1999) to calculate the inkjet printer AEC (Table 5-51).

Table 5-51: Inkjet Printer AEC Calculations

Inkjet	Active	Standby	Off	Sources
Power Draw, W	42.5[76]	13.3[77]	2.8[78]	Meyer and Schaltegger (1999), MACEBUR (1998), Kawamoto et al. (2001)
Usage, h/year	60	6,215	2,486	Tables G-1 through G-5 (see Appendix G)
		UEC, kW-h	92	
		AEC, TW-h	0.56	

Commercial inkjet printers account for about 10% of the electricity consumed by commercial printers.

[76] Equals the average "active" power draw of Meyer and Schaltegger (1999) and MACEBUR (1998).

[77] Equals the average of Meyer and Schaltegger (1999), MACEBUR (1998) and Kawamoto et al. (2001).

[78] Meyer & Schaltegger (1999)

5.5.6 Laser Printers

Each of the inkjet researchers also investigated laser printer energy consumption by mode, as did Wilkins & Hosni (2000). Table 5-52 presents their findings.

Table 5-52: Laser Printer Power Draw by Mode

Type	Active	Standby	Suspend	Off	Source
Laser	231	28	16	1.9	Meyer & Shaltegger (1999)
Laser	278	27	11	0	MACEBUR (1998)
Laser – Small Desktop	130	75	10	N/A	Wilkins & Hosni (2000)
Laser – Desktop	215	100	35	N/A	Wilkins & Hosni (2000)
Laser – Small Office	320	160	70	N/A	Wilkins & Hosni (2000)
Laser – Large Office	550	275	125	N/A	Wilkins & Hosni (2000)
Laser	N/A	77.0	25.0	1.0	Kawamoto et al. (2001)

Using the methodology of Kawamoto et al. (2001), outlined in detail in Appendix D, we account for laser printer "active" power consumption by adding 1W-h per image printed. In addition, we used the Wilkins & Hosni (2000) power draw data for "standby" and "sleep" modes, as their data offered a more detailed break-down of power draw by laser printer class (i.e., speed). The "off" values come from Kawamoto et al. (2001).

Table 5-53 displays annual usage by mode data from the three studies reporting usage[79], as well as the usage pattern used for the current study AEC.

Table 5-53: Laser Printer Annual Usage by Mode

Hours/year				
Active	**Standby**	**Suspend**	**Off**	**Source**
26	1,564	495	6,674	Meyer & Schaltegger (1999)
263	2,190	2,978	3,329	MACEBUR (1998)
N/A	5,081	1,635	2,044	Kawamoto et al. (2001)
N/A	**3,962**	**3,104**	**1,694**	**Current Study**

[79] Wilkins and Hosni (2000) only reported power draw by mode.

Tables G-1 through G-5 provide details of the usage calculations (see Appendix G).

Combination of the above usage times and Wilkins & Hosni (2000) power draw information yields the unit energy consumption (UEC) levels for each category of laser printer shown in Table 5-54. The product of the device UECs and the laser printer stock estimates (see Table 5-44) produce the laser printer AEC of 3.4TW-h *for non-printing modes* (see Table 5-55). Table 5-55 also contains our estimates of energy consumption during printing, which increases the total laser printer AEC to about 4.6TW-h.

Table 5-54: Laser Printer UEC Values, Not Including Imaging Energy, by Printer Class

Laser Category	UEC, kW-h/year
Laser Small Desktop	330
Laser Desktop	507
Laser Small Office	853
Laser Large Office	1,479
Color Laser[80]	507

Table 5-55: Laser Printer AEC, by Class and Total

Printer Category	Non-Printing AEC, TW-h	Printing AEC, TW-h	Total AEC, TW-h
Small Desktop (<12 ppm)	0.31	0.02	0.3
Desktop (13-29 ppm)	2.6	0.44	3.0
Small Office (30-69 ppm)	0.19	0.13	0.32
Large Office (70+ ppm)	0.02	0.66	0.68
Color Laser	0.28	0.01	0.29
TOTAL AEC[81], TW-h	3.4	1.25	4.6

5.5.7 Other Printers

"Other" printers include thermal and dye sublimation process devices, which are used for making photographic quality prints. We used power consumption values found at the Kodak and Mitsubishi-electronic web-sites[82] and applied inkjet printer usage levels. These devices consume less than one percent of the energy consumed by all printers (see Table 5-56).

[80] Assumed to be the same as a Desktop Laser printer. These printers are typically in the speed range of a desktop device when printing only in black. The Hewlett-Packard website (www.hp.com) publishes the print speeds of an HP Laserjet 8550 at 24 ppm B&W and 6 ppm color.

[81] This includes active (paper printing) energy consumption.

[82] www.kodak.com and www.mitsubishi.com .

Table 5-56: "Other" Printer AEC Calculations

Dot Matrix	Active	Suspend	Off	Source
Usage, h/year	60	6,681	2,019	Inkjet Usage (Meyer and Schaltegger, 1999)
Power Draw, W	122[83]	41	2	Kodak and Mitsubishi product specifications[84]
Total Energy Consumption, TW-h	0.05			

In practice, the estimate for "active" hours per year could be quite low, for instance, relative to usage in a one-hour photo shop. Nonetheless, the small stock of "other" printers means that even if the estimated quantity of "active" hours increased by a factor of ten, they would still account for only small portion of printer AEC.

5.5.8 Printer Energy Consumption Summary

Printers consume a total of 5.7TW-h (see Table 5-57).

Table 5-57: Total Printer AEC

Type	(TW-h)
Impact	0.37
Line	0.13
Other	0.05
Inkjet	0.56
Laser	4.6
TOTAL	**5.7**

[83] The active power is based on Wilkins and Hosni (2000) Nameplate:Actual ratio of 3:1. Low power is based on the Meyer & Schaltegger (1999) active to low power relationship of 3 to 1. Low power is an estimate.

[84] Specifications for the Mitsubishi CP700DE are found at http://www.mitsubishi-electric.com.au/products/print/cp700de.htm and specifications for the Kodak the thermal printer model 8660 are found at http://www.kodak.com.tw/TW/en/professional/products/printer/8660/specs.shtml

5.6 Computer Network Equipment

5.6.1 Background

Computer networks use a range of equipment that collectively connects the global Internet with millions of desktop computers. This equipment is generally divisible into two categories, LAN (Local Area Network, within a building or campus) and WAN (Wide Area Network, beyond the campus). LAN gear interconnects desktops and servers using private bandwidth, while WAN gear generally makes use of common carrier facilities to provide external access, either within a company (intranet), between companies (extranet), or to the global Internet. Figure 5-4 depicts typical deployment of computer networking equipment.

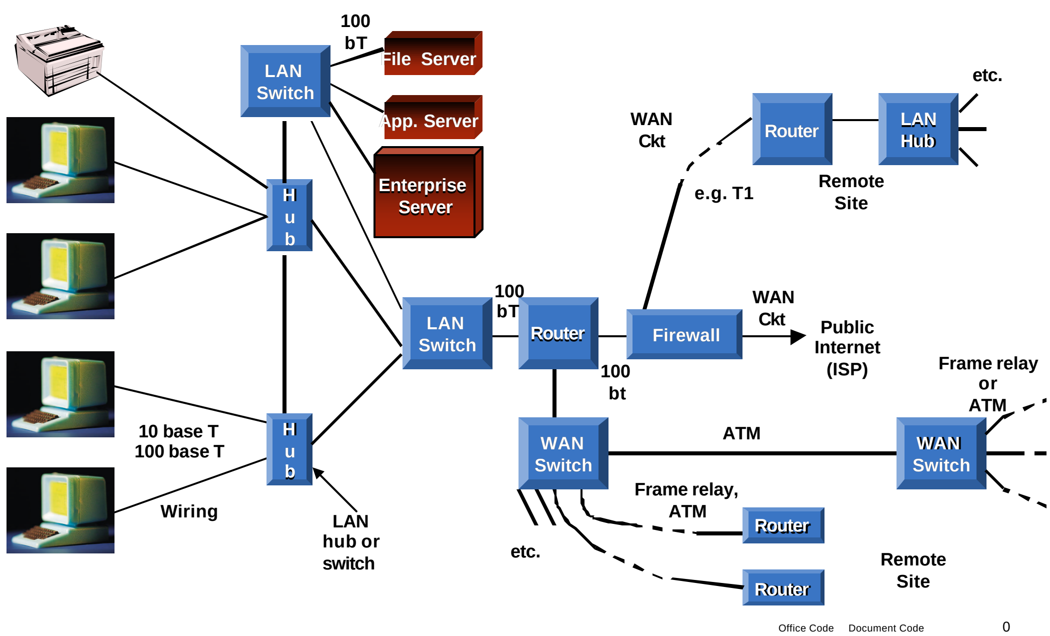

Figure 5-4: Computer Network Diagram

5.6.1.1 LAN Gear – Hubs and LAN Switches

Desktop computers are generally connected, via short in-building wiring, to some kind of hub. Whether this is a simple hub or a LAN switch, it is often a rack-mounted device that sits in a wiring closet, supporting as many as a few hundred ports in a single rack. Frequently the hub is a thin (2-3 RU) device which is designed for stacking into a rack. At the low end, desktop hubs for 4-8 connections can be small modem-sized boxes with external wall-wart power supplies.

In general, the term *hub* now applies most often to a simple type of equipment that operates at the physical layer of the protocol stack[85] and has all of the connected devices sharing a single pool of bandwidth. Functionally, it provides a physical connection between the local network and several devices, such as computers and printer shown in Figure 5-4. For instance, a basic 100 Megabit per second (Mbps) Ethernet hub has a single pool of 100 Mbps (shown at 100 base T) shared among (typically) 4-24 connections. Hubs were the predominant method of LAN connectivity through the mid-1990s, but most new installations use LAN switches. These somewhat more intelligent devices provide multiple paths between inputs and outputs, so that traffic between two nodes (such as, one desktop and one server) does not affect traffic between other nodes. Some switches operate at layer 2[86], looking at the Ethernet address; others now operate at layer 3 (IP address) or layer 4 (TCP socket). These higher-function switches provide additional security features that routers (see the discussion of routers in the following section on "WAN Gear") typically perform, but scaled down to be cost-effective on the LAN. The market is moving towards greater acceptance of higher-layer switching, as the price comes down closer to levels once occupied by simple hubs.

Commercial deployment of LANs began in the 1980s. The earliest form of Ethernet featured direct attachment of a transceiver to a thick coaxial cable, which provided the shared 10 Mbps pathway. Thinwire coaxial cable, using a hub arrangement, was introduced shortly afterwards but had only modest success in the office, though it is still used within wiring closets and some server rooms. Desktop wiring moved to twisted pair, using hubs, in the late 1980s. In the early 1990s, 100 Mbps Ethernet over twisted pair came to market and it has gradually whittled away share from the 10 Mbps version. A passive hub can sometimes support either speed but not both at the same time; a LAN switch can interconnect the two.

Ethernet had some competition, especially in the late 1980s, from IBM's Token Ring, which ran at 4 and then 16 Mbps over twisted pair, but that technology has faded fast. Alternative LAN technologies have had little success; FDDI (100 Mbps over fiber optics) saw some use on the campus backbone and Asynchronous Transfer Mode (ATM) briefly came into favor in the early 1990s, but neither is seeing much new LAN deployment. Today, Gigabit Ethernet (1,000 Mbps) stands at the leading edge of LAN bandwidth, and finds occasional use for campus

[85] http://foldoc.doc.ic.ac.uk/foldoc/foldoc.cgi?protocols explains a protocol stack as "A layered set of protocols that interact between the layers to provide network functions. Each intermediate protocol layer uses the layer below it to provide a service to the layer above."

[86] The following explanation of protocol layers and their functions comes from http://foldoc.doc.ic.ac.uk/foldoc/foldoc.cgi?protocol+layer. "The software and/or hardware environment of two or more communications devices or computers in which a particular network protocol operates. A network connection may be thought of as a set of more or less independent protocols, each in a different layer or level. The lowest layer governs direct host-to-host communication between the hardware at different hosts; the highest consists of user application programs. Each layer uses the layer beneath it and provides a service for the layer above. Each networking component hardware or software on one host uses protocols appropriate to its layer to communicate with the corresponding component (its "peer") on another host." For example, the TCP/IP (Transmission Control Protocol/Internet Protocol) protocol has five layers in its protocol stack.

backbones and high-end server links, and 10-Gigabit Ethernet looms on the horizon. These high-end technologies generally use optical fiber.

5.6.1.2 WAN Gear

Wide area networks (WANs) exist primarily to pass data between more remote locations - and typically at a lower layer level - than Local Area Networks (LANs), while remaining within a private network. Consequently, WANs typically use routers, which are packet switches operating at the IP layer (layer 3) which route the data to the appropriate IP address. Some WANs also employ WAN switches, which generally use Frame Relay and/or ATM to provide links below the IP layer. Separate discussions of each equipment type follows.

5.6.1.3 Routers

A router has a basic set of primary functions, including examining, filtering, and routing incoming data packets. Routers examine each incoming packet and determine where to send it, based on its IP (Internet Protocol) address. Today, the typical IP packet, with no specified options, can often be routed via specialized hardware, though more complex packets need to take the "slow path" through the router's main CPU. Routers also perform filtering, permitting or rejecting certain address ranges on specified interfaces, important network security functions. Route determination is another key router function: the router uses a specified protocol to determine the best path to every address within its own operator's network (autonomous system), with frequent exchanges of routing messages with other nodes in the network. A separate protocol exchanges routing information with other networks, an often complex function that is a major feature in WAN routers but not found in LAN switches that also operate at layer 3.

Current-day routers are generally stand-alone rack-mounted boxes, ranging in size from 1RU to full-rack systems. For instance, an ISP would typically have one or more large routers at each of its Points of Presence (PoP)[87] that interconnect the PoPs and connect to many dedicated-line subscribers. Large high-capacity routers with high-speed interfaces (such as OC-48[88]) serve on major backbone routes; subscriber connections more commonly use a large numbers of lower-speed interfaces (such as DS-1 to DS-3). At the subscriber locations, a small router, often a 1RU box or a desktop unit known as an "edge router", usually provides the connectivity. Corporate users and smaller ISPs typically have mid-sized routers, again typically rack-mounted but about the same size as a midrange server.

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[87] A Point-of-Presence is a location from where one can obtain access to the backbone of the Internet.

[88] OC stands for an "optical carrier" connection with 48-times the base capacity of 51.48MBps, or 2.488Gbps.

Routers emerged as commercial products in the mid-1980s, when TCP/IP[89] began to see commercial deployment in corporate networks. In the early days, minicomputers often performed routing, either dedicated or as a secondary function, but the advent of higher-speed links demanded dedicated hardware. Cisco and Wellfleet (now part of Nortel Networks) pioneered the industry with increasingly-powerful backbone routers; various other companies have had modest market share. Multi-protocol (TCP/IP, DECnet, Novell IPX, LAN bridging, etc.) routers became popular in the early 1990s, before TCP/IP became the dominant protocol. Newer routers are more likely to have value-added features within the TCP/IP protocol suite, such as quality of service enhancements, security features, etc. Cisco continues to dominate the core of both corporate and ISP networks. New vendors, such as Juniper, have begun to take away market share with new systems with aggregate capacities in the terabit range. Even large routers now tend to be single-shelf systems, albeit with different size shelves, but a few terabit systems are larger. At the other extreme, consumer routers using wall-wart power supplies that cost less than $200 have become popular in residences among cable modem and DSL users.

5.6.1.4 WAN Switches

Like routers, WAN switches help to manage the flow of large amounts of data between locations. They differ in their use of connection-oriented telecommunications protocols (ATM and Frame Relay instead of connectionless IP); some hybrid switch/router products provide both functions. Connection-oriented protocols offer superior flexibility for bandwidth allocation and defined Grade of Service (i.e., quality) applications, compared to raw IP, but these are not always required on public Internet applications.

WAN switches tend to be large devices used by phone service carriers, ISPs, or high-end enterprise customers and they occupy much of a rack. Often, they run on 48V DC, like telecom equipment, in contrast to routers (which primarily use AC power).

5.6.2 Computer Network Equipment Energy Consumption Summary

Computer network equipment consumes 6.4TW-h of electricity (see Figure 5-5), or only about 6% of all electricity consumed by non-residential office and telecommunications equipment.

[89] Transmission Communication Protocol/Internet Protocol, i.e., the communications protocol used for sending information over the Internet.

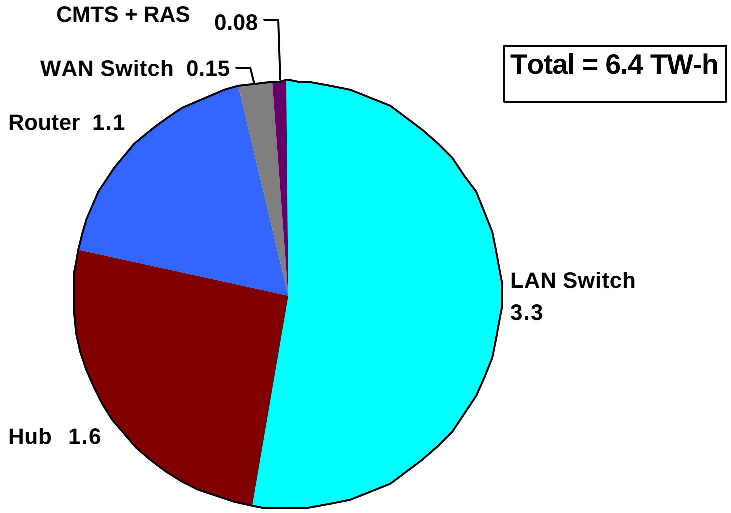

Figure 5-5: Computer Network Equipment AEC, in TW-h

LAN switches account for more than half of the computer network equipment AEC. Placed in the context of the ~133 million PCs installed in the U.S. (non-residential and residential; see Table 5-2), computer network equipment draws just over 5W per PC[90], or less than 5% of the average draw of a desktop PC and a 17-inch monitor in active mode.

The following sub-sections explain the derivation of the estimates by device.

5.6.3 Hub AEC

Silva (1998) projects the total number of hubs operating in the U.S.; in this case, a hub represent a single port, i.e., the two systems mentioned in the prior paragraph have 4-to-24 and 4-to-8 hubs each. Due to the dearth of hub power draw data, we measured the power draw of three hubs in the ADL computer network (see Table 5-58).

Table 5-58: Hub Power Draw Measurements, by ADL

Hub Model	Power Draw, W	Watt/Port	Comment
Synoptics LatticeNet	103W	1.23	Older vintage hub, circa 1994-95; 84 ports installed
Synoptics LatticeNet	108W	1.13	Older vintage hub, circa 1994-95; 96 ports installed

[90] Averaged over the 8,760 hours of computer network equipment annual operation.

Given the diversity of hubs deployed in computer networks, we developed an approximate energy consumption per hub. Table 5-59 presents hub AEC.

Table 5-59: Hub AEC Calculation

Quantity	Value	Source
Number of Hub Ports Installed, Millions	93.5 Million	Silva (1998); assumed all hubs installed in commercial buildingsa
Power Draw / Hub Port	1.25 Watts	ADL Estimate, based upon measurements
Operational Hours, Year	8,760	ADL Estimate
TOTAL AEC, TW-h	1.6TW-h	

5.6.4 LAN Switch AEC

LAN switches have experienced explosive growth over the past couple of years. Table 5-60 presents U.S. LAN Switch port shipment data from Dahlquist and Borovick (2000).

Table 5-60: LAN Switch Shipment and Stock Estimates (based upon Dahlquist and Borovick, 2000)

Year	LAN Switch Ports Shipped, Thousands	Source
1999	38,609	Dahlquist and Borovick (2000)
2000	51,321	Dahlquist and Borovick (2000)
LAN Switch Stock, Thousands	95,000	ADL Estimate, based on Dahlquist and Borovick (2000)

Dahlquist and Borovick (2000) also report data that show, on a global scale, sales of LAN switches in 1999 and 2000 almost equal their estimated global stock of LAN switches. Our U.S. LAN switch stock comes from applying the U.S. portion of 1999 LAN sales, 49%, to the remaining LAN switches.

Our power estimate comes from measurements we made of a late 1990s vintage LAN switch, divided by the number of ports to develop a Watts/port. Based upon industry knowledge, we assumed that the majority of ports are Fast Ethernet (100Mb) and up, some are GBE (Gigabit Ethernet), others 10Mb ethernet, and modified our estimate to reflect the range of equipment deployed. Table 5-61 presents the LAN switch AEC calculations based upon measurements made by ADL.

Table 5-61: LAN Switch AEC

Quantity	Value	Source
Power Draw/LAN Switch Port	4 Watts	ADL Measurement of Baystack 450: 69W (14 of 24 ports in use); 10/100Mb devices of late 1990s vintage; ADL Estimate[91]
Operational Hours, Week	168 Hours	Estimate; networks are always on
TOTAL AEC, TW-h	3.2TW-h	

As noted above, the LAN switch stock includes many different equipment sizes and speeds. Because the power draw estimate is based on only one measurement and an approximate draw of similar equipment, the LAN switch AEC has significant uncertainty, with a greater potential for lower (than higher) AEC than in Table 5-61.

5.6.5 WAN Switch AEC

WAN switches manage network traffic on wide-area networks and generally make use of common carrier facilities to provide external access, either within a company (intranet), between companies (extranet), or to the global Internet. In one common application, ISPs use WAN switches to aggregate DSLAM[92] traffic, dividing up bandwidth between the different DSLAMs. In practice, WAN switches are deployed by the shelf, with varying degrees of utilization of a shelf's full capacity. Table 5-62 summarizes the WAN Switch AEC calculation.

Table 5-62: WAN Switch AEC Calculation

Quantity	Value	Source
Number of Shelves Installed	50,000	Contact at Newbridge Networks, (13,000 shelves shipped by Alcatel; Alcatel has about 26% market share)
WAN Switch Lifetime	7 Years	ADL Estimate
Power Draw/Shelf	350 Watts	Contact at Newbridge Networks (480W for loaded shelf; ADL estimate of shelf utilization)
Operational Hours, Week	168 Hours	ADL Estimate
TOTAL AEC, TW-h	0.15TW-h	

[91] Note that the Cisco 2900 switch mentioned by Kawamoto et al. (2001) as a representative LAN switch has 28 ethernet interface ports and dissipates a maximum of 240W (product specification, www.cisco.com). If one applies the 37.5% ratio of measured-to-actual power draw of the Cisco 2500 router, the Cisco 2900 would draw on the order of 3W/port.

[92] DSLAMs (Digital Subscriber Line Access Multiplexers) aggregate numerous DSLs. Typically, a DSLAM aggregates numerous DSLs from a town, while a WAN switch aggregates traffic from several DSLAMs for an area.

5.6.6 Router AEC

The router stock equals the ITIC (2000) shipment data summed over an estimated four-year lifetime (see Table 5-63).

Table 5-63: Router Shipments, from ITIC (2000)

Year	Routers Shipped, Thousands
1997	403
1998	590
1999	952
2000	1,312
Router Stock, Thousands	3,257

To model energy consumption, we averaged a large number of lower-power edge routers (such as the Cisco 2500 series) with a smaller number of hub/core routers (such as the Cisco 7500 series) which serve in ISP backbones (see Table 5-64).

Table 5-64: Router AEC Calculation

Quantity	Value	Source
Average Router Power Draw	40 Watts	Measurements by Kunz (1997) showed 15W draw by both the Cisco 2503 and 2514 routers, compared to 40W maximum (Cisco 2500-Series Product Specification); 7505, 7507, 7513, and 7576 Series "typically" consume 600W, 900W, 1200W, and 1050W each (rated thermal outputs of 780, 945, 1600 and 1600W). [93]
Operational Hours, Week	168 Hours	ADL Estimate
TOTAL AEC, TW-h	1.1TW-h	

5.7 Uninterruptable Power Supplies (UPS)

5.7.1 Background

Although Uninterruptable Power Supplies (UPSs) are not office or telecommunications equipment in themselves, they play an increasingly important role in insuring the reliability of office and telecommunications equipment. UPSs are electronic devices through which power passes from the electric grid to critical electronic equipment to ensure the continuous flow of high quality power to the

[93] From www.cisco.com .

equipment. The major components of most UPSs are battery charger/rectifiers, standby batteries, and inverters. Table 5-65 outlines the range of UPS applications relevant to telecommunications and office equipment, as a function of UPS power capacity, quantified in kilo Volt-Amps (kVA).

Table 5-65: Typical UPS Applications as a Function of UPS Capacity (from Plante, 2000)

UPS Power Range, kVA	Typical Applications
<1 kVA	PCs, Workstations
1 - 5kVA	Multiple Computers, Servers
5 – 100kVA	Telecom Switching Centers, ISP, Data Networks
>100kVA	Larger Telecom Centers, Data Centers

Larger UPS supporting large file servers, clusters of servers, and network equipment (e.g., server farms) manage power quality, eliminating transient spikes or sags in power that could adversely impact the performance and/or damage electricity-consuming equipment. UPSs also provide back-up power in case of power service failure for a duration sufficient to last through the outage or bring back-up power generation online. At the low end, inexpensive (~$100) UPSs continuously manage power quality while also supplying several minutes back-up power to PCs or workstations to enable an orderly system shut-down if the power fails. UPSs now come in rack-mounted systems, facilitating integration of UPSs with systems such as network servers and data centers and enabling modular expansion of UPS capacity as demand grows.

UPS use in IT environments has grown substantially due to the increased financial impact of computer equipment downtime (e.g., upon lost e-commerce opportunities [business-to-business or person-to-business] during down periods). For example, Madsen (2000) estimates that one hour of downtime would result in the financial losses noted in Table 5-66; these values should be considered as the general magnitudes of potential loss.

Table 5-66: Potential Range of Losses per Hour of Down-Time (from Madsen, 2000).

Business Type	Estimated Losses per Hour of Down-Time, $U.S.
Stock Brokerage Firm	5-7M
Credit Card Services	2-3M
Phone 800 # Services	150-225K
Airline Reservation Services	50-75K
Cellular Phone Services	35-45K
Network Connection Services	25-30K
Bank ATM Service Fees	10-15K

In light of the economic issues outlined above, a growing trend is for UPSs to provide parallel redundant systems and power arrays to enhance system reliability. For example, many scaleable and rack-mounted UPSs deployments now offer "N+1" redundancy in case one UPS unit fails.

Clearly, the time required to transfer the power source to the UPS is a key quality that determines the effectiveness of the UPS in minimizing data losses. A discussion of how each type of UPS manages power follows.

5.7.1.1 Conventional UPS Systems

Stand-by and online systems constitute the two major categories of UPSs; as noted by APC (2001), a third class of UPSs, line interactive, typically function in a manner similar to stand-by systems. Typically, stand-by UPSs protect small loads. For example, the APC Back-UPS 500[94] has a maximum output rating of 500VA or 300W, or about twice the power consumed by a PC and its monitor, and can provide 150W for 13.2 minutes. Figure 5-6 (from APC, 2001) illustrates the operation of a basic standby UPS system, where electric power from the grid flows through the UPS and into the device.

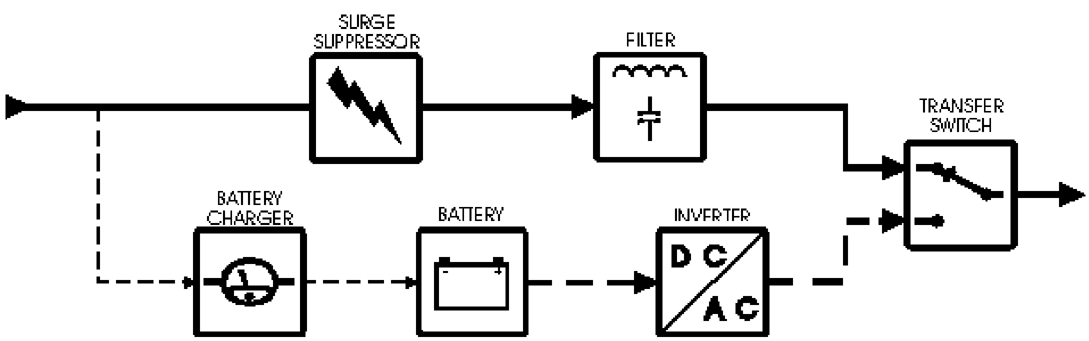

Figure 5-6: Standby UPS system schematic (shown in standard operational mode, from APC, 2001[95]).

In standard operational mode (i.e., with sufficient, clean power flowing from the electric grid), stand-by systems allow power to pass through the UPS and into the electronic device. As depicted in Figure 5-6, stand-by UPSs incorporate varying degrees of power conditioning, typically surge suppression to counter voltage spikes and a filter to reduce unwanted harmonics. If the UPS battery has run down from

[94] Product information found at the American Power Conversion web site, www.apc.com .

[95] See http://159.215.19.5/kbasewb2.nsf/For+External/6681E24551A75E388525672300568CB2?OpenDocument

use, the UPS battery charger will also charge the battery. When power ceases flowing to the device, the UPS detects the lack of electric power and the transfer rapidly establishes ("clamps") an electrical connection between the device and the battery power source to enable continued operation of the device. Stand-by systems typically consume only a few percent of the electronic device load because in default operational mode they allow power to pass through to the load with minimal power management.

A larger and popular variant of the stand-by UPS, the ferro-resonant UPS depicted in Figure 5-7, serves many devices in the 1-10kVA range.

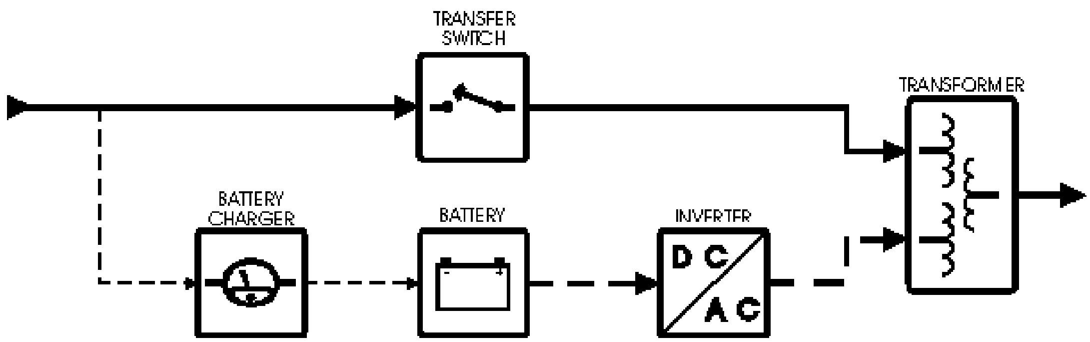

Figure 5-7: Ferro-Resonant UPS Schematic (from APC, 2001)[96]

Ferro-resonant UPSs have a special transformer that couples the line/battery power to the output. During normal operation, power flows from the AC power source, through a transfer switch and a transformer, and to the protected device(s). The transformer offers superior surge isolation, as well as power quality management. When the power fails, the transfer switch opens rapidly and the battery supplies the device load through the inverter. In contrast to standby UPS, the ferro-resonant UPS generates significant quantities of heat due to inefficiencies in the transformer.

Online UPS systems serve almost uniquely larger electronic devices, such as mainframe computers, blocks of servers, and key telecommunications equipment. Online systems offer superior power management and quality (frequency and voltage level) relative to smaller (non-ferro-resonant) stand-by UPSs.

[96] See http://159.215.19.5/kbasewb2.nsf/For+External/6681E24551A75E388525672300568CB2?OpenDocument

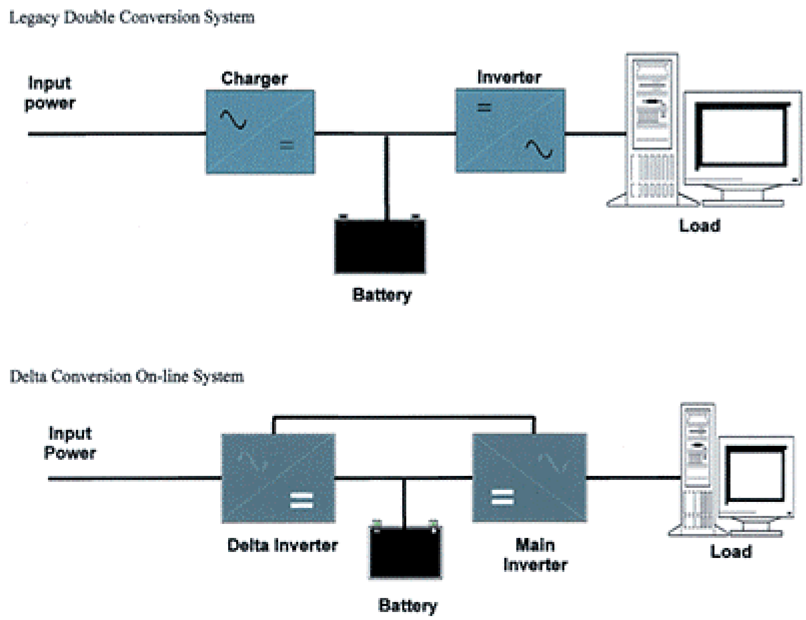

Figure 5-8: Online UPS Schematics (from Madsen, 2000[97])

As shown in Figure 5-8, an online UPS accepts AC commercial power, typically from the grid, that it conditions and rectifies (converts from AC to DC). Subsequently, the DC output feeds the battery and also passes through an inverter, converting the power back to well-conditioned AC power to satisfy the device load. If the "input" power fails, the battery continues to supply power to the inverter and provide high-quality power to the load without interruption, as it has no transfer switch. Online systems offer very high reliability but cost more than other UPS systems.

The precise way that the UPS functions has a significant impact upon the efficiency of the UPS. UPSs consume energy as they condition the power that flows through them. The actual amount of power consumed depends upon the actual load power draw, the rated power draw of the UPS, and the UPS technology. Power flowing through older "double" conversion systems shown above (the "Legacy Double Conversion System" in Figure 5-8) always is converted from AC to DC, and then back to AC, typically dissipating 10 to 15% of the power flow in heat when operating near its rated capacity. Newer systems, such as APC's "Delta Conversion System" (Figure 5-9), enable the power to largely by-pass the AC-DC-AC conversion process, as the UPS works primarily to supply the difference between the input and load powers. This enables delta-conversion systems to realize much higher efficiencies than double conversion systems, typically dissipating less than

[97] See http://www.energyusernews.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2584,14489,00.html

5% of power flow as heat when operating near its rated capacity. This technology can also improve the UPSs' power factor relative to highly-inductive technologies, such as ferro-resonant.

In practice, according to Madsen (2001), UPS efficiency also depends upon actual load "seen" by the UPS relative to the rated load. UPSs have a basic power demand for fans, power supplies, which establishes a "base" load. However, the electric components are sized for the full UPS power rating and dissipate less heat at smaller loads. The net results is that the overall UPS efficiency curve is pretty flat if the actual load falls between 50-100% of the rated load, but drops off below 50%, precipitously under 25%[98].

Madsen (2001) also indicates that UPSs tend to be oversized, often designed to 70-80% load on larger systems and typically operating at around 50% of peak load. Several reasons exist for this practice, including general design conservatism, allowances for future expansion, greater redundancy, longer load run-times after power failure, and parallel redundant systems for maintenance purposes. Note that in an information technology (IT) installation, the peak load usually includes only key IT equipment; designers typically figure that functions such as cooling can wait a few minutes until the back-up power (generator) comes online.

5.7.1.2 Other UPS Technologies and UPS Trends

Although lead-acid battery storage dominates the UPS energy storage market (Madsen, 2001, estimates they represent 99% of installed base), several other technologies have come to market. Flywheel designs store rotational energy in a rapidly-spinning wheel inside an evacuated enclosure supported by magnetic bearings. A "motor" adds energy by accelerating the flywheel and discharges energy from the flywheel via a generator, causing the flywheel to slow down. Flywheels provide reasonable short-term energy storage (typically less than a minute), very high power rates, and are more compact (i.e., higher energy density) than lead-acid batteries, albeit with somewhat lower efficiencies and higher costs than lead-acid batteries (ADL, 2000). Longer-term, they offer the potential for lower maintenance costs. Similarly, hybrid battery-flywheel designs have come to market, where the flywheel provides the energy for brief interruptions or shortfalls in power while batteries offer power for longer events. This minimizes the cycling of the batteries relative to battery-only systems, increasing the batteries' lifetimes.

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic fields of DC current passing through a storage coil. As the name implies, SMES systems feature a coil made of superconducting material cooled below its

[98] In data centers, where vacancies in mid-2001 often approach 80% (Mears and Pappalardo, 2001) and actual loads generally fall well short of expected loads, many UPS systems are likely operating well under 25% of their rated load. In these instances, UPS efficiencies plummet and UPSs count account for a large portion oftotal data center energy consumption.

critical temperature to decrease the coil's resistance down to negligible levels. American Superconductor has deployed SMES systems in very limited quantities but the technology is not yet mainstream. In time, SMES offers the potential for very high energy power levels in very large installations (e.g., utility-scale) with high energy density, albeit at greater expense. The cost of smaller SMES systems would tend to limit its applicability to UPS systems in IT applications.

Super capacitors, very large versions of the conventional electronic component, also offer very high storage densities and discharge rates. They could have a future as part of the largest UPSs but remain several years from commercialization.

"Smart" UPSs are becoming more common, incorporating more sophisticated power quality management, UPS and system diagnostics, data (e.g., power quality) logging, and communication with other devices, all through software/microprocessors. For example, when a "smart" UPS encounters a power problem, it will first try to manage the problem and diagnose its severity. If the "smart" UPS determines that the computer network needs to be shut down, it will communicate with the computer network to enable a (and often enact an automated) controlled system shut-down process to prevent data loss. If a back-up power source supports the failing system, the "smart" UPS systems communicates with the backup power source (genset) and signals to it to come on line. In addition, the system will contact the appropriate internal and external (service) people to fix the basic problem while logging a continuous record of the power problem.

5.7.2 UPS Stock

About 70% of UPS market serves IT- and telecommunications-related equipment (Madsen, 2001; Business Communications Company, Inc., 1998), while the rest of the devices support key facilities (hospitals), critical production (glass fiber, paper mill, long production run facilities, etc.), and personal computers in houses. We found three sources for UPS sales, summarized in Table 5-67.

Table 5-67: Global and North American UPS Sales Estimates

Year	Global UPS Sales, $U.S. (millions)		North American UPS Sales, $U.S. (millions)
	Business Communications Company, Inc. (1998)	Taylor and Hutchinson (1999)	Plante (2000)
1997	3,270	----	----
1998	----	3,877	----
1999	----	4,210	2,070
2000	----	4,573	2,529
2001	----	4,966	2,926
2002	5,600	5,393	3,219
2003		5,857	3,498
2004			3,794

UPS come in a wide range of sizes and technologies and Taylor and Hutchinson (1999) break down North American sales by equipment type and general size (see Tables 5-68 and 5-69).

Table 5-68: 1998 Break-Down of Global UPS Sales, from Taylor and Hutchinson (1999)

	Stand-By	On-Line	Interactive. Hybrid
$U.S.	461.9	2,120.0	1,295.1
%	11.9	54.7	33.4

Table 5-69: 1998 Break-Down of North American UPS Sales by <5kVA and 5kVA+ ranges, from Taylor and Hutchinson (1999)

	Stand-By	On-Line	Interactive. Hybrid	Total
Millions of $U.S., <5kVA Class	193	239	640	1,072
% of <5kVA Class	18	22.3	59.7	
Millions of $U.S., >5kVA Class	0	377	87	463[99]
% of >5kVA Class	0	81.3	18.7	

Plante (2000) provides further refinement of the shipment data within the <5kVA and >5kVA classes (see Tables 5-70 and 5-71).

[99] Note: Total does not equal sum due to rounding of numbers.

Table 5-70: Segmentation of UPS Sales in the <5kVA Class, by kVA (from Plante, 2000)

Power Range, kVA	% of 1999 Sales	1999 Sales, millions of $U.S.
<0.5 kVA	20	255
0.5-0.9 kVA	29	369
1.0-2.9 kVA	34	433
3.0-5.0 kVA	17	217
Total North American Sales in 1999, <5kVA UPS		1,274

Table 5-71: Segmentation of UPS Sales in the >5kVA Class, by kVA (from Plante, 2000)

Power Range, kVA	% of 1999 Sales	1999 Sales, millions of $U.S.
5.1-20 kVA	33	263
21-50 kVA	16	127
51-100 kVA	13	103
101-200 kVA	13	103
201-500 kVA	14	111
>500 kVA	11	88
Total North American Sales in 1999, >5kVA UPS		796[100]

In the analyses that follow, we assumed that the same distributions of the percentages of 1999 sales presented in Tables 5-70 and 5-71 hold for all years before and after 1999.

The North American shipment data of Plante (2000) and the sales segregation by UPS technology of Taylor and Hutchinson (1999) provide the backbone of our stock estimate. We used several informed assumptions to develop the UPS stock estimate. First, we assumed the different equipment lifetimes noted in Table 5-72, as suggested by Madsen (2001).

Table 5-72: UPS Lifetime Estimates (from Madsen, 2001)

UPS Technology	Lifetime Range Suggested by Madsen (2001), Years	Value Used, Years
Interactive	5-7	6
On-Line	10-12	11
Stand-By	5-7	6

[100] Note: Total does not equal sum due to rounding of numbers.

Second, we assumed that all stand-by UPS were in the <0.5kVA range (i.e., all stand-by UPS are simple systems deployed for a single computer). Third, from the general literature (and also the recommendation of Madsen, 2001), all UPSs over 20kVA are online devices. Fourth, we assume that the <5kVA class as a whole will grow in sales at a 10.5% CAGR[101]. Fifth, within the <5kVA class, <0.5kVA equipment sales grow at 9.2% CAGR and 3-5kVA equipment sales grow at 12.7% CAGR (Plante, 2000), allocating the remaining sales between the two other classes, per their portion of the <5kVA sales in 1999. Sixth, for UPSs >5kVA, we assumed that the sales distribution by class shown in Table 5-71 remains constant over time. The equipment lifetimes (Table 5-72) require back-casting of sales prior to 1998, was carried out by assuming the above forecasting assumptions also apply to back-casting sales by technology and power class. Appendix E includes additional details of the sales volume by technology and power class, over the years relevant to the lifetime of each device.

To translate the sales data into number of units, we researched typical sales prices of UPSs for each technology type in each power class. Sources of information included online sales by UPS manufacturers and UPS vendors (e.g., Egghead.com), as well as prior studies of larger UPSs (ADL, 2000). Tables 5-73, 5-74, and 5-75 summarize our price estimates, broken down by technology and power class. In each case, we attempted to find an average price for devices sized near the middle of the power class range.

Table 5-73: On-Line UPS Representative Models and Prices, by Power Class

Power Class, kVA	Average Price, $US	Representative Models
<0.5 kVA	210	Assumed same as interactive
0.5-0.9 kVA	718	Best Axxium 1kVA, RM
1.0-2.9 kVA	2,565	APC Symmetra 2kVA; Best Ferrups 2.1kVA
3.0-5.0 kVA	5,100	APC Symmetra RM 4kVA; Best Ferrups 4.3kVA
5.1-20 kVA	8,200	APC 10kVA Silicon; APC Symmetra 12kVA; Best Ferrups 800 7kVA; Best Ferrups 18kVA
21-50 kVA	20,840	APC 30kVA Silicon; Best Unity 30kVA and 40kVA
51-100 kVA	28,200	APC 60kVA Silicon
101-200 kVA	51,600	APC Silicon 120kVA, Best Unity (3-Phase)
201-500 kVA	96,000	APC Silicon 240kVA, Best Unity (3-Phase)
>500kVA	175,000	APC 500kVA Silicon

[101] Plante (2000) projects a 12.8% CAGR for units over that period; we assumed ~2%/year price discount.

Based upon these prices, we estimated the total number of online units sold of each type from 1990 through 2000, displayed in Figure 5-9.

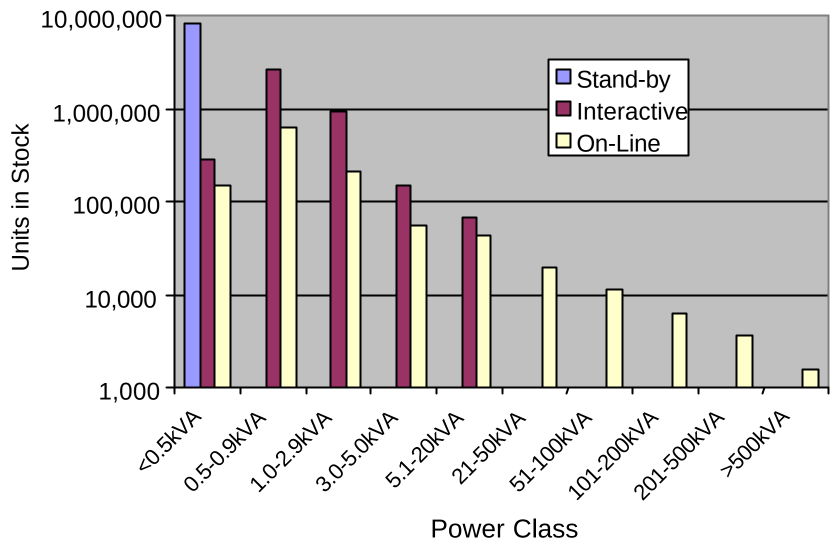

Figure 5-9: UPS IT/Telecoms UPS Stock, by Technology and Power Class

Similarly, Table 5-74 presents typical prices for interactive units in the different power classes.

Table 5-74: Interactive UPS Representative Models and Prices, by Power Class

Power Class, kVA	Average Price, $US	Representative Models
<0.5 kVA	210	Smart UPS 420
0.5-0.9 kVA	325	APC Smart UPS 700
1.0-2.9 kVA	1,069	APC Smart UPS 2200; Best Fortress 2.2kVA, standard and RM
3.0-5.0 kVA	3,257	APC Smart UPS 5000, APC Matrix 5000XR
5.1-20 kVA	5,798	APC Smart UPS DP 10000

When combined with sales projections, the prices from Table 5-74 yield the annual unit sales estimates from 1995-2000, and the sum of units the stock break-down exhibited in Figure 5-9.

Lastly, we used the standby UPS prices from Table 5-75 to derive the standby UPS stock displayed in Figure 5-9.

Table 5-75: Standby UPS Representative Models and Prices, by Power Class

Power Class, kVA	Average Price	Representative Models
<0.5 kVA	$87	APC Back-UPS Pro USB 500, APC Back-UPS Office 500; Best Patriot 250VA

The "IT and Telecoms Stock" estimate shown in Figure 5-9 subtracts the ~30% of all UPSs functioning in other applications from the total stock, assuming that these "other" applications have the same distribution of UPSs by technology and power class as IT and telecoms applications. Because the UPS stock estimate is for North America, we further assumed that the U.S. has 90% of all UPSs in North America.

5.7.3 Power Consumption

UPS manufacturers provide estimates of UPS efficiency at full load. However, as discussed in the prior section, most UPSs operate well below full load and suffer some efficiency degradation at that point. Madsen (2001) recommended using the values tabulated in Table 5-76 to estimate the efficiency of different technologies.

Table 5-76: Approximate UPS Efficiency, by Technology (from Madsen, 2001)

Technology	Efficiency Range	Efficiency Used	Comments
Standby	90 – 95%	92.5%	
Interactive	90 – 95%	92.5%	
On-Line	80 – 85%	82.5%	Most of stock double-conversion units (~70-75%)

Combining the earlier assumption that all UPS are loaded to 50% of their rated maximum, the stock information in Figure 5-9, the mean maximum power ratings of the representative UPS systems in Tables 5-73, 5-74 and 5-75, and the efficiency values above yields the estimated UPS AEC in Table 5-77.

Table 5-77: UPS Annual electricity consumption

UPS Technology	AEC, TW-h
Standby	0.8
Interactive	1.2
On-Line	3.8
TOTAL AEC, TW-h	5.8

UPSs currently consume a substantial amount of energy (5.8TW-h) and promise to consume more in the future as the growth of e-commerce increases the potential losses from power quality interruptions and increases the stock of UPSs.

5.8 Telephone Network Equipment

5.8.1 Background

Telephone networks differ from computer networks in that they primarily carry voice information instead of data. We have organized our energy analysis of telephone switching equipment into four categories, based upon the primary function of that portion of the network. The *transmission* network includes the long-distance fiber optic connections between major cities and locations handling most long-distance telephone calls. *Mobile telephone networks* include the base stations (in towers) which connect mobile telephones to the larger phone network. The *public phone network* denotes the established copper wire connections between telephone companies' central offices and residences and buildings. Lastly, *private branch exchanges (PBX)* are private in-house phone systems, typically found in a larger office buildings or campus setting.

Although all telephone systems were originally designed primarily to carry voice traffic, the distinction has become increasingly blurred since the advent of the Internet. For example, local public telephone networks originating from central office now provide Internet access via dial-up modems and long-distance fiber optic transmission networks originally installed to handle voice traffic now carry Internet data. Mobile phone networks have begun to offer some basic web access, notably in Japan and Europe.

Figure 5-10 presents a simplified diagram of the key telecommunications equipment of the different telecommunication networks and how they interconnect. Each enclosed area represents a discrete physical site that contains (at a bare minimum) the equipment depicted within the box. The lines running between boxes signify interconnections; dash-dot represents a connection carrying primarily Internet traffic, while the "plain" lines carry a mixture of voice and data traffic. Figure 5-10 also clarifies the physical type of connection, as the circles with the two enclosed arrows denote (typically) fiber optic connections; all other connections are copper wires.

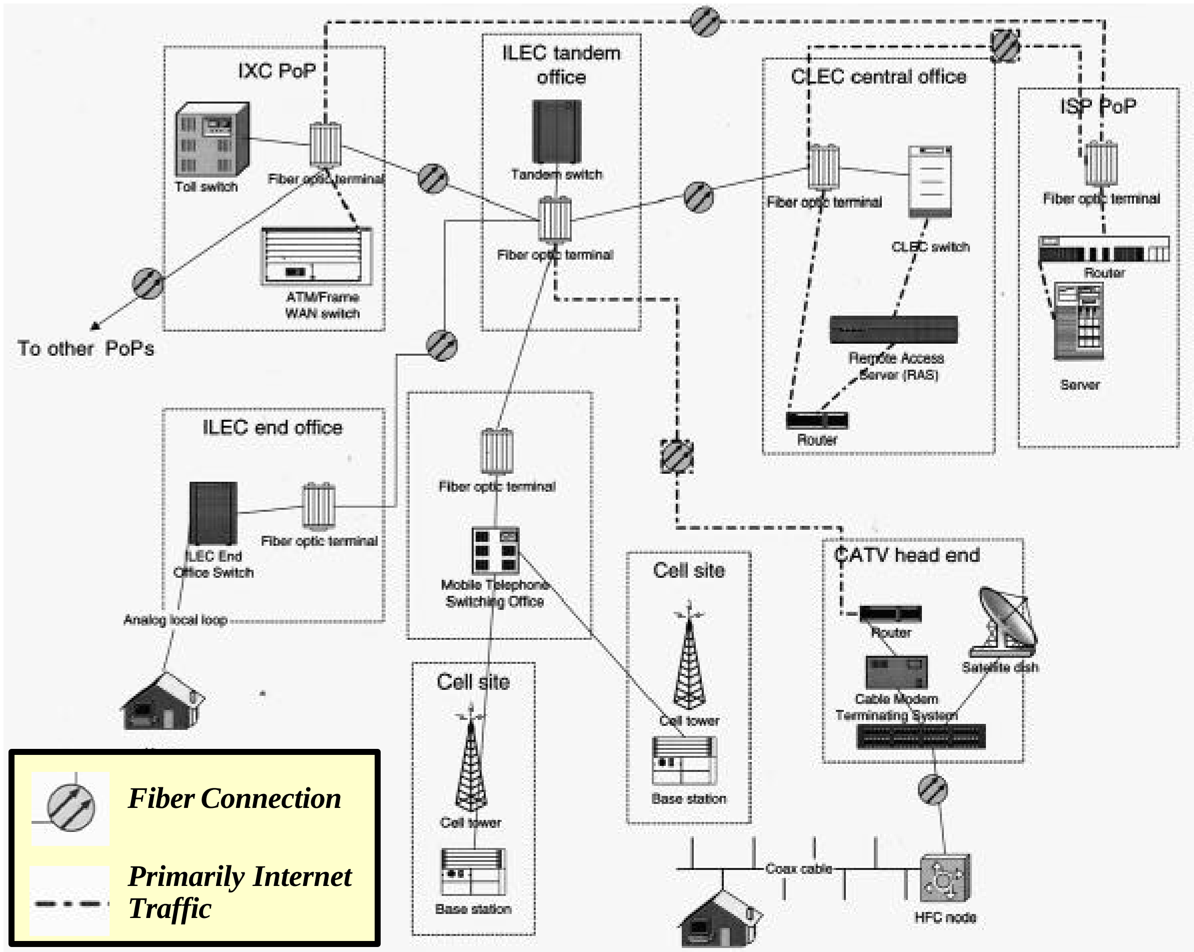

Figure 5-10: Simplified Telephone Network Diagram (for Illustrative Purposes)

We have organized our discussion of the different telephone networks by the physical locations of equipment shown in Figure 5-10. In reality, telecommunications networks are far more complex than shown, with a wide range of equipment deployed at different locations, particularly in central offices (COs). In addition, competing companies will often house equipment at the same physical site, a practice known as "co-location".

- An Interexchange Carrier Point of Presence (IXC PoP) provides access from the public phone network to different long-distance phone companies (e.g., AT&T, Sprint, etc.). Each one has a toll switch (usually one or two) that carries telephone calls, fiber optic terminals (often quite a few), and often has WAN data service switches (frame relay and asynchronous mode transfer [ATM] technologies). The fibers leaving the IXC PoP connect the PoP to the company's other PoPs as well as to other carriers, including: Incumbent Local Exchange Carrier (ILEC, e.g., AT&T); Competitive Local Exchange Carriers

(CLECs, i.e., recent phone companies that compete with the incumbents), Internet Service Providers (ISPs), and other large customers.

- The *ILEC Tandem Office* is the hub of an ILEC's local network. It generally contains numerous fiber optic terminals and a tandem switch, which is a telephone switch with no analog-line terminals. An ILEC has one or more tandem offices in a Local Access and Transport Area (LATA); for example, the Massachusetts LATA has seven tandem offices.

- The *ILEC End Offices* are a part of the public telephone network that serves retail ILEC subscribers for a small service area. Typically, each one contains a telephone switch and numerous copper local loops to subscribers. It usually has modest fiber optic capacity, but may also use fiber optics to connect to remote digital line concentors (not shown in diagram), which provide the analog loops to neighborhoods not immediately adjacent to the building.

- The *CLEC Central Office* is the hub of a CLEC's regional network. It generally consists of one or more telephone switches, which provide local service to a region (more akin to an ILEC tandem office than to an end office). Each one has fiber optic terminals to interconnect it with the ILEC tandem offices in the region, as well as to connect to its own subscribers (either via the ILEC's, its own, or another carrier's facilities). CLECs generally provide collocation space to ISPs who put their Remote Access Servers (RASs) there. Multiple RASs will feed an ISP's router, which uses dedicated bandwidth to the ISP's own PoP.

- The *ISP PoP*, an Internet Service Provider's Point of Presence, generally has direct fiber optic connections to long-haul bandwidth providers (such as the IXC) and local bandwidth providers (such as local CLECs or the ILEC) who, in turn, connect to the ISP's regional customers. The PoP contains the ISP's servers and routers, which interconnect it with the ISP's other PoPs as well as other ISPs' peering points.

- The *Mobile Telephone Switching Office* is a wireless telephone company's regional switching center. It has fiber optic bandwidth to the ILEC tandem offices and, perhaps, an IXC, with additional connections to the various cell sites that it serves. Each *Cell Site* contains base station radio transmission gear (analog and/or digital), with the number of transmitters and their power dependent upon the cell size, location, and chosen radio technology. The transmission gear is located as close as possible to the antenna, such as in a hut at the foot of a tower. In an effort to minimize the aesthetic impact of cell towers, church belfries have become common cites for cellular antennae. Cell sites are characterized by their size (i.e., essentially their broadcasting power and effective receiving and transmission radius), ranging from large macro cells to much smaller pico cells.

- The Cable TV (*CATV) Head End* functions as the hub of a cable television company's local network. Its service area is generally larger than that of an ILEC end office, but often smaller than that served by a tandem office. When the current Hybrid Fiber-Coax (HFC) technology is in use as diagrammed, fiber runs directly from the head end to neighborhood *nodes*, which then convert from analog fiber to analog coaxial able for the final drop to number of homes (typically in the 250-to 2,000-foot range). A *Cable Modem Termination System* (CMTS) delivers cable modem service at the head end, which, separately for each remote node, modulates data onto a reserved TV channel. This allows the cable Internet service and cable TV video to share the HFC distribution, which usually originates from the broadcast airwaves and satellites.

5.8.2 Telephone Network Equipment Energy Consumption Summary

Each of the four segments of the telephone network has different energy-consuming elements. Cellular transmission gear accounts for the bulk of mobile telephone network energy consumption. Fiber optic equipment in ILECs, CLECs, and IXC PoPs consumes most of the energy consumed by the transmission network. ILEC analog phone lines to residences and businesses dominate energy consumption of the public telephone network. Commercial phone systems, such as those made by Lucent and Nortel, drive the energy consumption of private branch exchanges (PBXs).

Telephone network equipment consumes approximately 6.6TW-h of electricity (see Figure 5-11), or only about 6% of all electricity consumed by non-residential office and telecommunications equipment. Placed in the context of the ~133 million PCs installed in the U.S. (non-residential and residential; see Table 5-2), telephone network equipment draws just over 5W per PC[102], or less than 5% of the average draw of a desktop PC and a 17-inch monitor in active mode.

[102] Averaged over the 8,760 hours of computer network equipment annual operation.

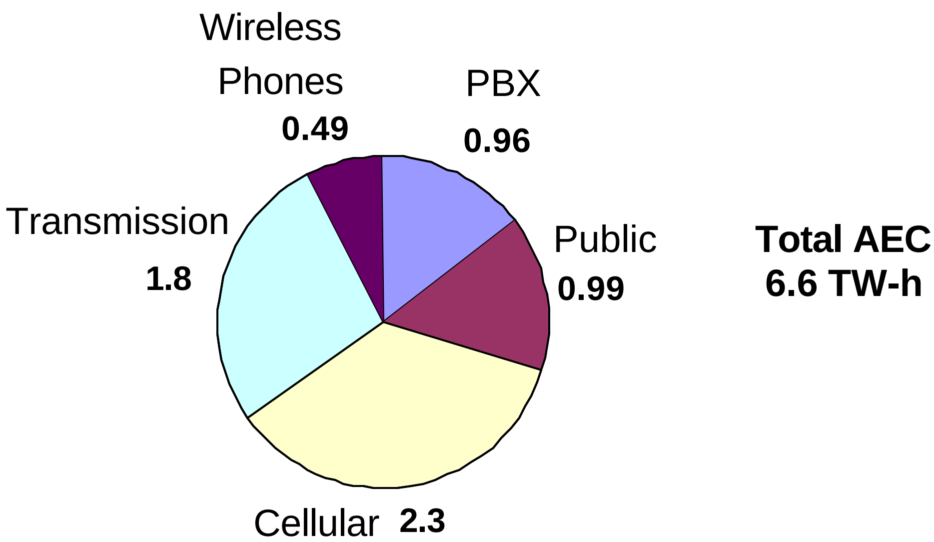

Figure 5-11: Telephone Network Equipment AEC, in TW-h

The subsequent sections explain the basis for the calculations in more detail.

5.8.3 Public Telephone Network

Ideally, a public telephone network AEC estimate would reflect a bottom-up calculation, starting with the stocks of different types of switching equipment and multiplying each stock by its measured power draw to calculate an AEC. Unfortunately, this proved impossible within the scope of this project for several reasons. First, the sheer variety of switching equipment, in vintage, scale and complexity, makes identification of "typical" classes of installations very difficult. Second, data on equipment stocks are not publicly available in a way that captures their installed configurations. Third, equipment power draw data do not exist in the public domain and phone companies loathe to part with this confidential information.

In the past, researchers (Koomey et al., 1999) have developed approximate estimates of national telephony energy consumption based upon energy consumption per dial equivalent minutes (DEMs). However, Blazek (2001) notes that this approach likely embodies substantial errors. Specifically, the data cited by Koomey et al. (1999) reflects energy purchases (*not* the same as energy consumed) from a single CO for a period Y1998, and does not segregate telecoms and non-telecoms (mainly HVAC[103]) energy consumption. In any case, the Koomey et al. (1999) estimate would include all telecoms equipment (i.e., not just public network), as well as any computer network equipment in the CO (e.g., trunk routers, WAN switches).

Our public phone network AEC estimate relied upon a different approach. Based upon industry experience, we identified that the analog phones[104] dominate the energy consumption of the public telephone network. Data from FCC (2000a) suggested that the approximately 180 million phone lines reported in 1998 would continue to grow at about 4% per year to almost 195 million lines in Y2000, of which about 166 million lines are analog lines (ADL estimate). Phone lines only draw power upon establishing a connection between two phones (i.e., when a call is completed), so that each phone only draws, on average, a fraction of the ~3W per active phone line. Ty Stowe (2000), a former power engineer for Bell South, estimated that each new analog line requires an average of 0.68W in additional capacity. This number represents the incremental power required to power additional line at peak demand and embodies a large margin (factor of ~2.5) to ensure that the CO will continue to function if portions of the power plant go off-line. Based on 0.68W/line, the Public Phone consumes approximately 1.0TW-h of electricity (Table 5-78).

Table 5-78: Public Telephone Network AEC Calculation

Quantity	Number	Source
Number of Analog Public Telephone Lines	166 Million	ADL estimate, based upon FCC (2000a)
Average Power Draw, Watts / Line	0.68	Stowe (2000)
Active Hours per Year	8,760	ADL Estimate
AEC, TW-h	0.99TW-h	

In reality, power draw probably does not scale linearly with the number of lines; however, the greater the portion of switch AEC attributed to analog lines, the better the linear assumption becomes. Similarly, if analog line consumption dominates energy consumption, the large safety factor, coupled with the fact that the draw represents a peak (not an average) draw, suggest that the actual public phone network AEC might be lower than the 1.0TW-h estimate.

[103] Johansson (1993) presented AEC data for three Swedish telephone exchanges and found that telecoms equipment accounted for 47, 51, and 42% of total electricity consumption, with the rest mainly HVAC. In warmer climates, i.e., in most of the U.S., cooling loads increase and would presumably increase HVAC electricity consumption. Blazek (2001) confirmed that HVAC could consume ~50% of all CO electricity.

[104] Switches power analog phone lines, but the analog line components account for much of the power draw of switches; other switch elements include common equipment (e.g., one administrative module per switch) and line equipment (e.g., concentration modules, trunk ports).

5.8.4 Private Branch Exchanges (PBXs)

Private Branch Exchanges (PBXs) are internal phone networks that reside in businesses. As with the public phone network, we had hoped to perform a bottom-up calculation of PBX AEC. Unfortunately, we could not obtain sales nor stock data of PBXs that would reflect the wide range of PBXs (by vintage and size, i.e., number of subscribers) operating in commercial buildings.

Instead, we obtained the PBX subscriber installed base from MMTA (2000) and developed an estimate of power draw per subscriber. Meyer and Schaltegger (1999) reported PBX power draw measurements for a range of PBX capacities (see Table 5-79).

Table 5-79: PBX Power Draw Data (from Meyer and Schaltegger, 1999)

PBX Size (# of Subscribers)	Power Draw (W)	W / Subscriber[105]
2 to 19	23.9	2.3
20 to 99	106.8	1.8
100 to 499	446	1.5
500+	2589	N/A

We supplemented the measured data by considering additional PBXs of different vintages and sizes to develop a power draw estimate of 1.96W per subscriber (see Table 5-80). PBXs operate "around-the-clock", yielding a 0.96TW-h AEC estimate.

Table 5-80: Private Branch Exchange AEC Calculation

Quantity	Value	Source
PBX Subscribers	55,920,000	MMTA (2000)
Power Draw/Subscriber, Watts	1.96	ADL Estimate, based upon Meyer & Schaltegger (1999) and Several Equipment Vintages
Operational Hours/Week	168	ADL Estimate
Total AEC, TW-h		0.99

[105] Using the mid-point of the subscriber range; PBXs often do not operate near their full capacity

5.8.5 Transmission Networks

The original long-distance transmission networks used copper wire and began deploying microwave towers in the 1950s. In the 1980s, fiber conversion began, buoyed by the enhanced signal quality and much higher bandwidth of fiber versus microwave service, and most long-distance traffic now passes through fiber[106]. The current U.S. fiber network consists of numerous "trunk" routes between major hubs in each state, with fiber beginning to supplement and replace copper wire to major facilities (e.g., office buildings), to take advantage of the higher voice and data bandwidth afforded by fiber.

Fiber optic communication systems transmit data by taking electronic signals (such as voice signals or data packets) and "translating" them into intermittent laser-generated light pulses. The light pulses pass through a glass fiber wrapped in plastic (multiple fibers combined together make a fiber optic cable) to a receiver, where they are re-translated back into electronic pulses. If the light signal must pass through a very long distance, the signal intensity and quality begins to deteriorate, necessitating an amplifier to restore the signal to its original quality and intensity. As the quality of fiber optic devices has improved, the distance required between amplifiers has grown (in Y2000, to around 80km).

Fiber terminals, which send, receive, and multiplex data (e.g., to a T1 connection), dominate the energy consumption of fiber optic networks, primarily due to their lasers[107]. Unfortunately, we could not find data for shipments of terminals; instead, we developed an estimate for the number of terminals in both local and long-distance (trunk) fiber optic networks. Table 5-81 succinctly summarized the fiber optic terminal count and the following paragraphs explain the count in detail.

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[106] Microwave towers remain in use for remote locations, where the cost of laying fiber over longer distances for low levels of traffic becomes excessive.

[107] We also examined long-distance amplifiers, devices which re-generate the light signals as they weaken while passing through the fiber. Based upon industry expertise and evaluation of the approximate length of fiber optic sheath laid *and lit* by major long-distance players (AT&T, Sprint, etc.) and the approximate distance between amplifiers, on the order of 50 miles, we estimated a stock of about 3,000 amplifiers. Discussions with equipment vendors yielded a power draw of ~200W per amplifier (i.e., about the same as a terminal), and an AEC of 0.005TW-h, much less than the 1.8TW-h consumed by terminals.

Table 5-81: Summary of Fiber Optic Terminal Count

Location	Number of Terminals, 1998	Source
ILECs, Inside the Plant (Central Office)	363,124	ADL Estimate, based upon FCC (2000b)
ILECs, Outside the Plant (e.g., in manholes, pedestals)	100,000[108]	ADL Estimate, based upon various FCC Sources
ILEC DS1/DS3Terminals	230,556	ADL Estimate, based upon FCC (2000b)
Commercial Buildings	64,534	FCC (1999)
CAPs, in Central Offices	19,360	ADL Estimate, based upon FCC (1999)
Interexchange Carriers	51,603	ADL Estimate, based upon FCC (1999)
TOTAL, 1998	829,177	
TOTAL, 2000 (25% growth assumed)	1,036,472	

The FCC (2000b) reported that the ILECs had 2,178,743 strands of fiber in their loop plant as of a 1999 count, with an average cross section of 45.3 strands per sheath. They also reported that 74,451 RBOC (regional Bell operating company) pedestals had fiber connections in 1998[109]. Based upon industry experience, we estimate that each terminal, on average, serves six fiber loop plant strands, which translates into 363,124 terminals in the central offices. We expect that these tend to be lower-speed terminals (often OC-3), because they serve individual buildings, neighborhood pedestals, and other localized voice-intensive uses. The mix of "inside" (CO, or central office) and "outside" (anywhere else, including customer sites) terminals is not completely clear, and this number could be low. In addition, we estimated the number of devices used to serve DS1 and DS3 terminals (also known as T1 and T3 lines).

FCC (2000a) states that competitive access provider (CAP) penetration in 1998 to 64,534 buildings, each of which we presume has a terminal. We assume that these are often on fiber rings that string multiple remote terminals onto a CO site, so we estimate a 1:10 ratio of CAPs to CO sites, and thus 6,453 CAP CO sites (some just remote terminals themselves). Our assumption of three terminals per site yields 19,360 CAPs inside (CO) terminals.

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[108] This count may be somewhat low due to co-location of terminals in manholes. Blazek (2001) indicates that co-location occurs often in Northern California, but we believe it to be fairly uncommon on a national basis.

[109] Ameritech did not report data.

To estimate the number of fiber terminals operating in the long-distance sector, we used FCC (2000a) numbers for each major IXC's average number of fibers per sheath, multiplied by the number of Points of Presence, and then by the FCC's percentage-of-fibers-lit number. Table 5-82 contains the IXC stock calculations, including ADL estimates for some numbers that the FCC left blank.

Table 5-82: Estimated Number of Fiber-Optic Terminals by Interexchange Carrier, from FCC (2000a)

Interexchange Carrier	Fibers / Sheath	% Fibers Lit	PoPs	Number of Fiber-Optic Terminals
AT&T	32.7	50	1074	17,560
Frontier	23.3	8	59	110
GST	68.9	2	689	949
IXC Comm	19.3	20	110	425
Level3[110]	96*	20*	49*	941
MCI	48	65	500*	15,600
NEON	65.7	5	5	16
Norlight	19.3	20	20	77
Qwest	45.4	25*	65	738
Sprint	20	85	400*	6,800
Williams	97.7	10	52	508
Worldcom	48*	67	245	7,879
Note: * denotes ADL Estimates.			TOTAL	51,603

The final estimate of 51,603 lit strands and the assignment of one terminal per strand reflected the assumption that each pair of strands required a terminal at each end.

As noted earlier, we could not obtain shipment data for fiber optic terminals, preventing generation of a bottom-up AEC estimate. Instead, we developed the fiber optic terminal power draw based upon discussions with major equipment vendors. Based upon information provided by technical contact at Nortel, we estimated an average draw of 200W per terminal, which takes into account draw of 1-1/2 to 3-1/2 amps per shelf per side (at 48 volts); in the worst-case scenario, each shelf would draw 6-9 amps. Fiber optic terminals often have redundant configurations, with left and right sides of each shelf on separate power sources, where the active side draws more current than the hot-standby side. Power draw varies minimally with actual throughput and the terminals remain “hot” all the time. The entire population of fiber optic terminals consumes approximately 1.8 TW-h (see Table 5-83).

[110] ADL Estimates for Level 3; Level 3 not included in FCC data.

Table 5-83: Fiber Optic Terminal AEC Calculations

Parameter	Value
Number of Terminals	1,036,472
Power Draw, Watts	200
Hours / Year	8,760
AEC, TW-h	1.8

Newer terminals are more efficient on a watt-per-bit basis, but draw more power than older terminals due to their greater throughput. For instance, a marketing manager at Ciena stated that their recent Dense Wavelength Division Multiplexing[111] (DWDM) equipment draws ~35W per wavelength at OC-48 and 60W at OC-192. Although these faster devices account for much of the money presently spent on fiber optic equipment, they do not account for a large portion of the fiber optic terminals in service in Y2000.

5.8.6 Cell Site Equipment

We calculated cell site power consumption for each type (size) of cell site, focusing upon the power consumed by the transmitters that broadcast information to wireless users. CTIA (2000) information suggests that approximately 100,000 cell sites[112] were in service as of 4Q00, which agrees closely with the estimate of Blazewicz (2001). Table 5-84 breaks out the cell site AEC calculations by cell size.

Table 5-84: Cell Site Equipment AEC Calculations

Cell Type	Number of Cell Sites	Average Power Draw, W	AEC, TW-h	Sources, Number of Cell Sites & Power Draw
Macro	30,000	5,000	1.3	Blazewicz (2001); Plateberg (2001)
Mini	45,000	2,000	0.79	Blazewicz (2001); ADL Estimate
Micro and Pico	25,000	1,000	0.22	Blazewicz (2001); ADL Estimate
Total Cell Site Equipment AEC, TW-h			2.3	

According to Plateberg (2001), the peak power consumption of a large ("macro") cell site can be as much as 9-10kW, based upon observed busy draws of approximately 400A at 24V. The same observer notes that he sees "typically" 200-250A during the day, and lower nighttime power levels, leading us to select an

[111] Dense Wavelength Division Multiplexing technology increases the bandwidth of a fiber optic cable by enabling multiple lasers generating light signals at different wavelengths to pass through the same fiber optic strand. A multiplexer separates the different signals on the output end.

[112] A "site" connotes a discrete equipment installation by a single wireless provider. Thus, if a single physical tower contained cell site equipment for three companies (i.e., colocation, a rather common practice), CTIA counts that as *three* cell sites.

"average" draw of 5kW. Blazewicz (2001) assigns 30% of cell sites to the macro category, which generally contain both analog and digital equipment. "Mini" cell sites, which are sometimes referred to as remote terminals, are engineered with roughly 200A of rectifier capacity, and can draw 4kW during peak-hours. We are assigning them an "average" of 2kW and, per Blazewicz (20001), assigned 45% of cell sites to this category. These sites may be mixed analog/digital or digital-only. "Micro" and "pico" sites do not have full-power transmitters, because they only cover small geographic areas. We estimate their power draw at 1 kW, with 25% of sites in this category. “Micro” and “pico” sites generally possess only digital equipment. The average cell site equipment draws 2,650W/cell.

The cell site AEC of 2.3TW-h ranks as the largest component of telephone network energy consumption.

5.9 Annual Electricity Consumption Relative to Commercial Building and National Energy Consumption

Table 5-85 places the 97-TW-h of electricity consumed by commercial office and telecommunications equipment in Y2000 in the context of the commercial sector and national energy consumption.

Table 5-85: Comparison of Non-Residential Office and Telecommunications Equipment Energy Use to Commercial Building and National Energy Use

Sector	Electricity Consumed, TW-h	Primary Energy Consumed, Quads	Source
Non-Residential Office and Telecommunications Equipment	97	1.07 [113]	Current Report
Commercial Buildings Total	1,100	16.0	BTS (2001)
National Total	3,607[114]	97.7	EIA (2001c)

Office and communications equipment consumes about 2.7% of delivered electricity nationwide, or just less than 9% of all electricity consumed in commercial buildings. On a primary energy basis (electricity and other fuels), non-residential office and telecommunications equipment AEC represents just over 1% of national energy consumption, or almost 7% of commercial building primary AEC.

[113] Based upon a primary-to-electricity conversion ratio of 10,958 Btu per kW-h (BTS, 2001).

[114] The 3,607TW-h figure represents “Total End Use” electricity consumption for Y2000. It equals the sum of “electric utility retails sales” (3,398TW-h) and “nonutility power producers” (208TW-h).

5.10 "Internet" Energy Consumption Upper Bound

Estimating the energy consumption of the "Internet" is difficult, primarily because the boundaries of the Internet are not clear. For instance, what portion of telephony network AEC contributes to the Internet AEC? What fraction of commercial PC AEC counts as Internet electricity consumption? Does the energy consumed to manufacture Internet-related equipment contribute to Internet energy consumption?

We calculated an upper bound on energy consumed by the Internet by summing the energy consumed *directly* by all office and telecommunications equipment that is potentially associated with the Internet. In addition to equipment studied in Section 5, the estimate also includes all residential and commercial office and telecoms equipment except printers and copiers, as well as broadband Internet access devices, smart handheld devices, and internet appliances (Table 5-86).

Table 5-86: Upper Bound Estimate of "Internet" AEC

Equipment Class	AEC, TW-h	Source
Commercial Internet-Related Equipment[115]	72	Current Report
Residential Internet-related Equipment[116]	5.9[117]	Kawamoto et al. (2001)
Residential Broadband Internet Access	0.28	
DSL	0.11[118]	Subscribers: NITA (2000) UEC: Rosen and Meier (2000)
Cable Modem	0.17[119]	Subscribers: NITA (2000) Power Draw: Manufacturer literature
Residential Wireless Phones	1.1[120]	Subscribers: Pottorf and Vyas (2000) UEC: Current Study
Residential Smart Handheld Devices	0.0012	UEC: Current study Stock: House and Hwang (2001)
Internet Appliances	1.9	See Appendix H
UPPER BOUND "Internet" AEC	**81**	

[115] Includes: PCs (desktop and laptop), Monitors, General Displays, Server Computers, Data Storage, Computer Network Equipment, Telephone Network Equipment, UPSs, Smart Handheld Devices, Workstations.

[116] Includes (Using terminology of Kawamoto et al., 2001): PCs (desktop and portable), Displays.

[117] Preliminary data shared by Meier (2001) shows a range of 8 to 28TW-h for the relevant equipment, with very large uncertainties in equipment usage.

[118] NITA (2000) indicates an installed base of 1.57 million DSL subscribers; per Rosen and Meier (2000), we assumed that each DSL installation was assumed to consume 70kW-h/year.

[119] NITA (2000) indicates an installed base of 2.37 million cable modem subscribers. The Motorola SB4100 Cable Modem draws 9W (nominal; from Motorola product literature available at: www.motorola.com), while the COM21 DOXport 1110 Cable Modem draws 7W (max). The UEC calculation reflects 8W power draw per cable modem, over 8,760 hours per year ("always on").

[120] Pottorf and Vyas (2000) estimate 61.6 million "consumer" subscribers.

All together, the "Internet" directly consumed no more than 81[121]TW-h of electricity in Y2000, or ~2.3% of all electricity consumed in Y2000.

[121] Preliminary data from Meier (2001) suggest a range of 8 to 28TW-h for residential office equipment AEC, suggesting an upper bound of 103 TW-h.

6 Comparison of Current Study to Prior Studies

6.1 Summary of Prior Studies

At various points in time, several researchers have developed estimates of the nationwide energy consumed by the office equipment in commercial buildings. Figure 6-1 compares the bottom-line results of each of the studies, plotted against the year of the calculation. Table 6-1 outlines what equipment types other studies omitted as compared to the current study.

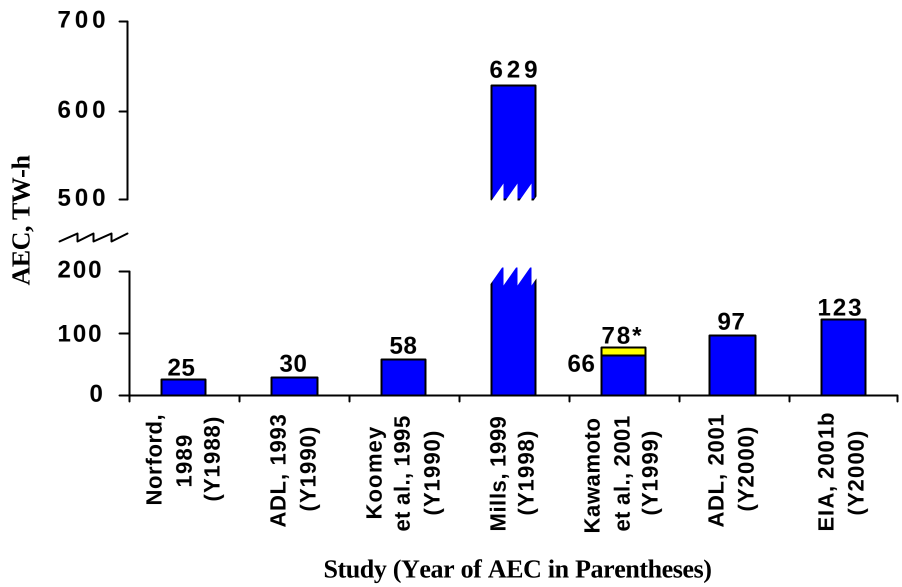

Figure 6-1: Comparison of Office and Telecommunications Equipment AECs of Different Studies (AEC years shown) [122]

[122] The 66 TW-h value reflects that shown in Kawamoto et al. (2001).

* The 78TW-h value shown for Kawamoto et al. (2001) equals the sum of the Kawamoto et al. (2001) value and the telephone central office (CO) AEC estimate of 12TW-h from Koomey et al. (1999).

Table 6-1: Comparison of Equipment Analyzed in Prior Studies to Current Study.

Study	Year	Equipment Considered
Norford et al. (1989)	1988	Personal computers, monitors, and printers
ADL (1993)	1990	Computers (mainframe, workstation, desktop, laptop), printers, typewriters, copiers, and facsimile machines
Koomey et al. (1995)	1990	Same as current study excepting: computer network equipment, telephone network equipment, UPS, and several smaller end-use devices (e.g., ATMs, scanners, adding machines, VSATS, etc.)
Mills (1999)	1998	PCs ("@ office", "used in commercial Internet service support"), server computers ("Internet information suppliers"), routers, and public telephone network (scaled up for the ~25K "telephone central offices" in the U.S.); Printers, UPS, monitors unclear; No copiers.
EIA (2001b)	2000	PCs and office equipment (i.e., "typewriters, copiers, cash registers, computer terminals, personal computers, printers, mainframe computer systems, and other miscellaneous office equipment"), most server computers[123]; No telephone or computer network equipment, UPSs, ATMs.
Kawamoto et al. (2001)	2000	Monitors, general displays, PCs (desktop and laptop), server computers, data storage, laser printers, inkjet printers, dot matrix printers, copy machines, computer network equipment, facsimile machines

Norford et al. (1989) used stock information and projections combined with power measurements and technology assumptions to develop their bottom-up Y1988 estimates as well as “saturation”, “new services”, and “efficiency” scenario projections for Y1995. The ADL (1993) bottom-up study, which includes several additional types of office equipment, produced a similar estimate for Y1990.

Koomey et al. (1995), building upon the work of Piette et al. (1995), developed Y1990 energy consumption estimates, as well as three projections for Y2000 and Y2010: “business-as-usual”, “ENERGY STAR®, Most-Likely”, and “Advanced.” Their 1990 estimates came in significantly higher than Norford (1989) and ADL (1993), reflecting the inclusion of more equipment types. Koomey et al. (1995) also used a more top-down methodology, applying power draw information for devices to surveys of equipment densities in commercial buildings, and then using national commercial building floorspace estimates to calculate the total annual electricity consumption.

Huber and Mills (1999) authored a three-page article presenting their estimates of the Y1999 energy consumption of the “Internet,” followed by a report by Mills

[123] Boedecker (2001) indicates that the CBECS survey includes servers located in computer rooms; this will count servers in data centers, as the EIA classifies data centers as office buildings.

(1999). Their calculation includes estimates of the energy consumed to produce devices connected to the Internet, home and office PCs connected to the Internet (including some peripherals), as well as Internet servers, computer network equipment, and a portion (40%) of telephone central offices. After isolating the portions of their calculation relevant to the current study and making a few adjustments (see Section 6.3), their AEC estimate of 628TW-h far exceeds that presented by any other studies. Section 6.3 compares the current study results with those of Mills (1999).

Kawamoto et al. (2001) completed a bottom-up analysis of energy consumption by office equipment and computer network equipment in residential, commercial, and industrial buildings for Y1999. Their study found that the relevant equipment consumed almost 66TW-h (78TW-h including the telephone central office AEC rough estimate of Koomey et al., 1999), or about 2% of all electricity consumed that year. Considering only equipment types included in both studies[124], the current study AEC comes in 19% higher than Kawamoto et al. (2001). Section 6.2 discusses the differences on the equipment level between the studies.

The Energy Information Administration developed projections for Y2000 and future electricity consumption by office equipment in commercial buildings (see Figure 6-2; EIA,2001b). Their Y2000 estimate of ~123TW-h exceeds that of the current study and Kawamoto et al. (2001), but does not approach the level of Mills (1999).

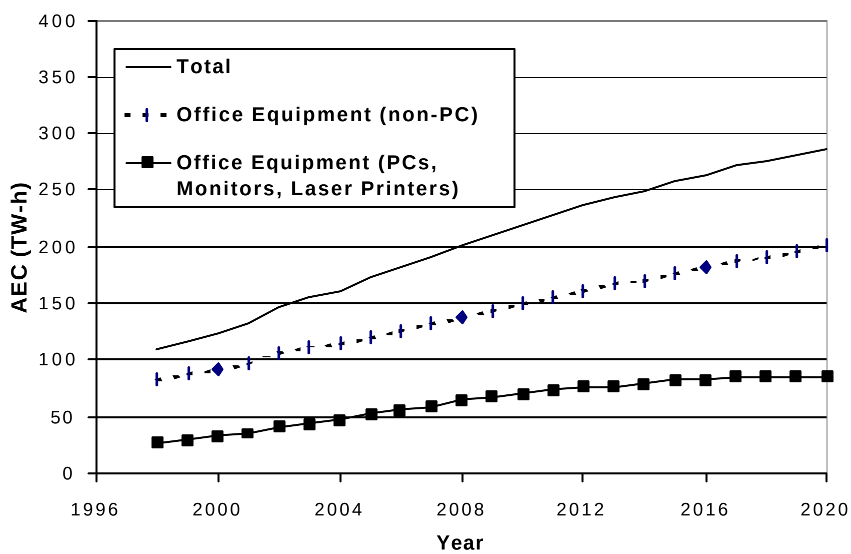

Figure 6-2: EIA (2001b) Projections of Office Equipment AEC

[124] PCs (desktop and laptop), monitors, general displays, laser printers, inkjet/dot matrix printers, copy machines, server/mainframe/mini computers, data storage, facsimile machines, computer network equipment.

Two of the studies, Kawamoto et al. (2001) and Mills (1999), are of sufficiently recent vintage (Y1999 and Y1998 AEC estimates) to make meaningful comparison with the current study possible. The following two sections compare the current study to those two recent studies in more detail in order to clarify the differences between studies, particularly between the current effort and the much higher AEC estimate of Mills (1999).

6.2 Comparison to Kawamoto et al. (2001)

Figure 6-3 compares the current study results, broken down by equipment type, to Kawamoto et al. (2001)[125] and clearly illustrates where differences between the studies arise. Table 6-2 explains the primary reason(s) for the differences.

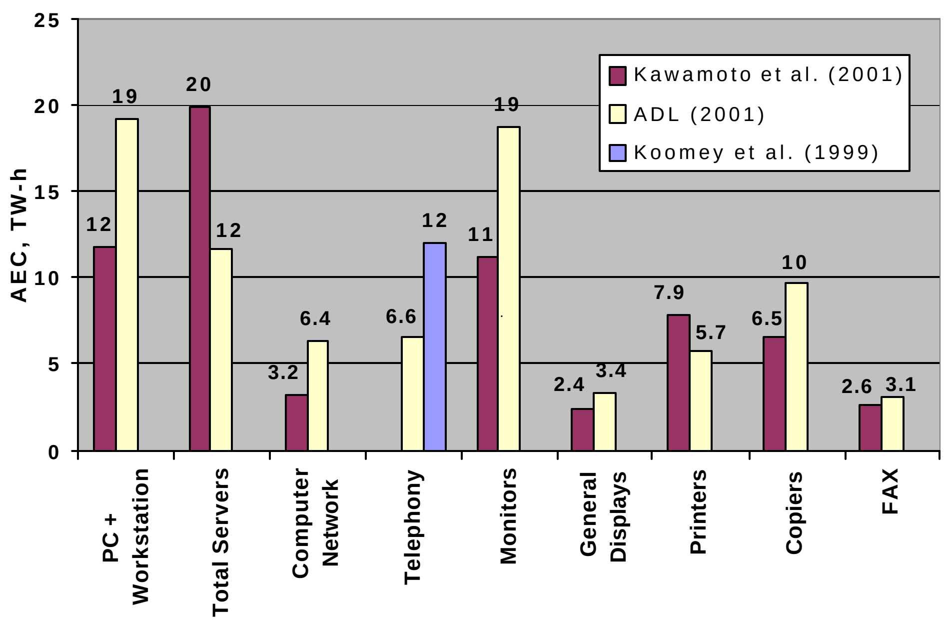

Figure 6-3: Comparison of AECs by Device - Kawamoto et al. (2001) and Current Study

[125] It also includes the telephone central office (CO) AEC estimate authored by the same group, from Koomey et al. (1999).

Table 6-2: Explanation of AEC Differences - Kawamoto et al. (2001) and Current Study

Equipment Type	% Difference in AEC, Kawamoto et al. (2001) relative to Current Study	Primary Reasons *Kawamoto et al (2001)* AEC Differs from Current Study
Monitors and General Displays	-39%	About 40% lower UEC – higher night/weekend off rates (for same power draw); ~10% smaller stock; different stock break-downs
PCs – Desktop (includes workstations)	-39% (-33% for only PCs)	About 28% lower UEC – higher night/weekend off rates; ~7% smaller stock; does not segregate workstations
PCs – Laptop	-61%	About 50% smaller stock; 10% lower UEC – higher night/weekend off rates
Server Computers	+71%	Larger stocks for “mainframe” and “minicomputers” due to 8- and 9-year lifetimes (versus 5 and 7, respectively); 100-200% higher power draw by “mainframes”
Printers	+33%	3.2 times larger laser printer stock; 66% fewer laser printer images
Copy Machines	-32%	17% smaller stock; lower UEC from higher night/weekend off rates
Computer Network Equipment	-49%	Different methodologies make differences difficult to discern; apparently, lower device stocks, particularly Routers and LAN Switches
Telephone Network Equipment	+82%	Different methodologies; Koomey et al. (1999) does not include equipment powered outside of the CO; their estimate *does* include non-telecom energy, e.g., HVAC.
Facsimile Machines	-17%	11% less time “on” per week; 7% smaller stock

With the exception of computer network equipment, the reasons for the differences between the two studies hinges primarily on additional night-status data not available to Kawamoto et al. (2001). For several equipment types, the current study AEC exceeds the Kawamoto et al. (2001) AEC because the current study uses more recent night-status data from Webber et al. (2001) that reported higher night-on and (in some cases) lower power-management enabled rates than used in Kawamoto et al. The current study also consulted several sources not used by Kawamoto et al. (2001) (e.g., Frasco [1999], Su [1999], and Josselyn et al. [2000]) that yielded different equipment stocks, most notably for laser printers and servers.

The computer network AECs proved difficult to compare as Kawamoto et al. (2001) relied upon sales figures and their estimates of the power draw by representative equipment to calculate AEC. Data provided by Koomey (2001) revealed that they estimated much smaller quantities of both LAN switch (and hub) ports, which is not surprising considering the large increase in LAN switch ports in Y2000. On the other hand, the router stock estimates do not differ greatly; the current study applies a somewhat higher average power draw for routers, resulting in a higher router AEC estimate.

Overall, the current study takes into account a wider range of data sources, uses a more refined breakdown of several equipment types, and considers a broader range of equipment than Kawamoto et al. (2001), leading to a more accurate and comprehensive AEC estimate.

6.3 Comparison to Mills (1999)

Mills' (1999) AEC far exceeded that of any other study. In addition, Mills attempts to quantify only energy consumed by the "Internet," making direct comparison of their results to this study problematic. On a device level, Mills consistently exceeds the AEC estimates of the current study, often by more than an order of magnitude (Figure 6-4).

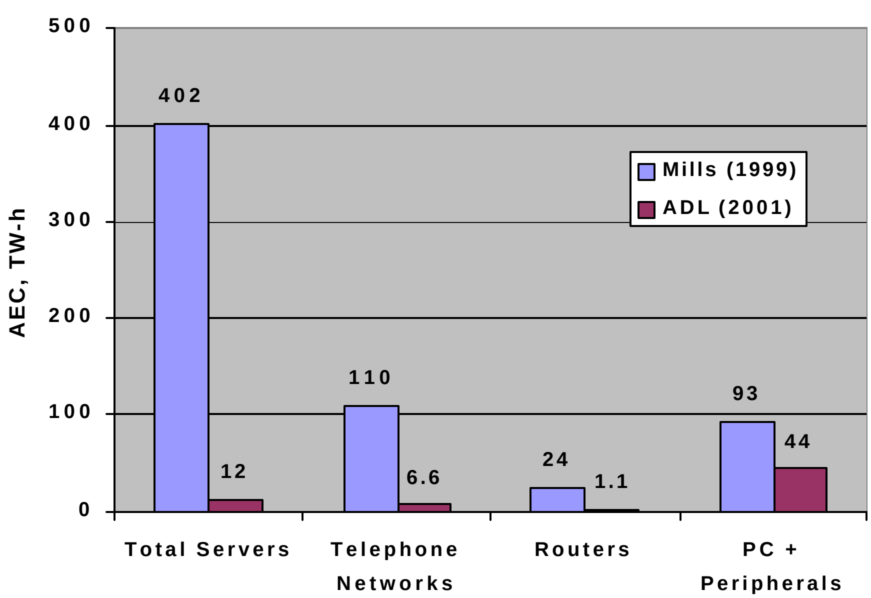

Figure 6-4: Comparison of AECs by Device - Mills and Current Study

The preceding figure reflects the best interpretation of the data provided by Mills (1999) within the context of the equipment categories considered in the current study. Most notably, the Mills (1999) AEC estimates reflect only the portion of equipment (typically 40%) he considered Internet-related. We extrapolated Mills' AEC values to reflect his installed base estimates for commercial equipment (see Table 6-3; the table footnotes provide calculation details).

Table 6-3: Explanation of AEC Differences - Mills (1999) and Current Study

Equipment Type	AEC, TW-h		% Variation	Primary Reasons *Mills (1999)* AEC Differs from Current Study
	Mills	ADL		
PCs, Workstations, and Peripherals (including Network Peripherals)	93[126]	44[127]	+98%	1kW PC+monitor[128] power draw versus ~0.15kW; different usage; 35% smaller stock
Server Computers, Including Data Storage	402[129]	11.6	+3,450%	Low-End: Assumes 1.5kW versus 0.125kW; High-End: 250kW versus 2.5kW
Routers	24	1.1	+2,000%	Assumes 1kW per router versus 40W
Telephone Central Offices	110[130]	6.6	+1570%	Assumes 500kW per CO; does not segregate equipment by device type and does not include telephony equipment outside of CO

Mills (1999) consistently selects power draw levels that lie at or beyond the end of the equipment considered and applies that assumption to the entire stock of devices. For example, Mills assumes that the average PC and peripherals consume 1kW.

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[126]Mills (1999) only takes into account usage during a 12-hour period per week for "PC @ office"" ascribed to the Internet – it is not clear if this does or does not include printers. A linear extrapolation of the "PC @ office" sub-category to a 40-hour work week results in an AEC equal to 70TW-h for that sub-category, and a total of 93TW-h for this category. Increasing the PC stock to 58.6 million in combination with the 40-hour a week extrapolation increases to 120TW-h for the "PC @ office"" sub-category, 143TW-h for the entire category.

[127] Includes desktop and laptop PCs, workstations, monitors, laser printers; it is not entirely clear whether or not Mills (1999) includes monitor and/or laser printer energy consumption.

[128] It is not entirely clear whether or not Mills (1999) includes monitor energy consumption in his calculations.

[129] Mills (1999) only takes into account ~33,000 mainframes in the "Major dot-com companies" breakdown. Extrapolating the Mills power draw to their stated population of 160,000 mainframes (350TW-h) and adding in the 52TW-h fo "Web Sites" server computers and peripherals increases Mills' server computer AEC to about 400TW-h.

[130]Mills (1999) represents the total AEC of all COs, using his stated values of 25,000 COs drawing an average of 250kW, whereas the current study segregates AEC by equipment type (public, transmission, etc.). Brad Allenby (1999), the Vice President, Environment, Health and Safety for AT&T, testified that the average telephone call consumes 0.005kW-h per minute of conversation at the central office. The FCC (2000a) reported almost 3,962 billion Dial Equipment Minutes (DEMs) of phone calls in 1998, consuming ~22TW-h. Koomey et al. (1999) cite a value of 0.0033kW-h/minute from a source at a "major telephone company", which translates into ~12TW-h (according to Blazek, 2001, this includes HVAC electricity). According to Blazek (2001), both of these estimates would include HVAC energy consumption, which can equal 50% of an exchange's AEC (Johansson, 1993). Either way, Mills' estimate greatly exceeds other estimates of telephone network AEC.

From our data, this assumption would be true – but only for a PC with a large CRT monitor, hooked up to a computer network, and printing continuously from an office-class laser printer. In reality, most printers are shared resources and do not print continuously. Similarly, the router power consumption of 1.0 kW/router applies to the high-end Cisco 7000-series routers. However, low-end routers dominate the router stock (e.g., the Cisco 2500-series) and draw 15W. Finally, the peak power draw of the high-end servers included in the server computer study can approach the assumed 250kW, but only for the most potent supercomputers (e.g., the Cray T3E; see Section 5.2.5).

The consistent use of extremely high power draw values clearly compromises the relevance of the Mills (1999) estimates.

7 Energy Consumption Projections for Key Equipment Types in 2005 and 2010

Numerous variables will impact the energy consumption of office and telecommunications equipment five and ten years hence, i.e., Y2005 and Y2010. Most equipment lifetimes are less than five years, implying bulk of the equipment stocks turn over at least once before 2005. Moreover, IT technologies continue to evolve very rapidly – so, too, can the device power draw characteristics. Finally, the future projections of equipment stocks can vary widely depending upon the introduction and novel application of technology (e.g., the commercialization of the Internet circa 1995), which are perhaps the most difficult variables to predict and take into account.

We developed three scenarios to attempt to account for the influence of these and numerous other variables upon our energy consumption projections for Y2005 and Y2010. The use of scenarios offers several advantages over single-point predictions:

- A wide range of possible values, enabling consideration of the impact of each
- Identification of key drivers (economic, technological, societal, political) for the future
- Vision creation for the possible technologies that may influence the future
- Identification of signposts for each scenario that help to identify the scenario that is actually coming to pass

The following section presents the three scenarios our team developed: "Ubiquitous Computing," "The PC Reigns," and "The Greening of IT." The scenarios are told retrospectively by commentator in Y2010.

7.1 Future Scenarios – 2010, A Look Back

7.1.1 Ubiquitous Computing

Our lives became thoroughly integrated with IT. The exuberance of the late 1990s, when people fawned over mundane content ineffectively delivered over the Internet, pales in comparison to the real, human-centered revolution that has taken place over the past decade. Global telecommunications companies became the primary drivers for the current degree of IT in our lives. They were driven by a need to fill the fiber optic bandwidth glut that developed in the early 00's and also to realize a return on their massive investment in 3G wireless telephony licenses. These giants developed and began deploying Personal Local Area Networks, or PLANs, to create an "always on" and "always aware" area around each person that enable information exchange between personal devices and the myriad of wired devices in the local environment. Initially, consumers rebelled at the real and perceived loss of privacy. Passage of the Digital Personal Information Protection Act (D-PIPA) in 2004 ceded control of the flow of information to the people and insured the security of information transfer via strong encryption protocols. Over the last five years, PLANs that automatically sense and connect user-approved devices within their range to the very-high bandwidth LANs came into widespread usage in the office and home environments. By 2009, most office buildings had PLANs, as did 28% of all U.S. households.

Breakthroughs in speech recognition software, driven by dramatic increases in computing power, played a key role in the pervasion of IT devices throughout the home and workplace by making human-device interfaces orders of magnitude more intuitive, intelligent, and simple. In a world that stressed agility and mobility, high-powered 2Mb/s 3.5G wireless phones and 200 gram configurable electronic tablets (CETs) often displaced the clunky PC as the gateways to the interconnected world, run by software-configured and optimized chip architectures. Last year, 4G telephone service saw initial deployment in Japan, a harbinger of new communications capabilities to come in the States. As the inexorably aging baby-boomer generation approaches retirement age, many decided to drop out once again, working less and working even more from the home via multi-media telecommuting, increasing the need for effective information exchange between work and home, a functioned filled by PLANs. PLANs also moved into retail spaces, where low-cost compact display screens and merchandise-specific "pico-LANS" provide enticing and up-to-date information to consumers – when the consumer wants it. Long-heralded, virtual reality has begun to become a reality. For instance, SmartHelp™, a proprietary "pico-LAN" information system that enabled virtual reality experiences with items ranging from clothes to lawn mowers and made many sales staff redundant, began real-world blurring of the "bricks and mortar" and "virtual" storefronts. As it occurred in Europe several years ago, electronic payments have become the *de facto* standard, while information agents now simplify the retrieval and delivery of information to people. The healthcare profession, facing unacceptable escalation of costs, adopted PLANs on an even greater scale to monitor patients in hospitals and homes.

The rise of PLANs and their tight integration with so much of peoples' lives led to striking increases in the cost and irritation of failures by devices (e.g., household servers) underlying PLANs. In response, people and companies moved away from unreliable operating systems and an over-burdened electric grid to the use of equipment, such as Uninterruptable Power Supplies (UPSs) and on-site high-quality power generation, to ensure network redundancy and reliability for the backbone and key elements of the ubiquitous computing society. To support the proliferation of PLANs, extensive data centers evolved to serve companies and residences alike, providing more and more powerful servers to manage the two hundred-fold increase in data storage and transmission over the past ten years as people's lives became progressively more integrated with IT.

7.1.2 The PC Reigns

Circa 2000, many forecasters predicted the downfall of the personal computer, believing that wireless phones or smart handheld devices would replace the large and cumbersome PC. How they were wrong! What they could not anticipate was that people would come to view the PC as *the* interface to network with the rest of the world and for office functions. Small devices simply could not offer effective displays relative to the proven and inexpensive CRT, nor match the computing power, needed to run successively more complex software and effectively manage the deluge of data, incorporated into very low-cost PCs. Paralleling the trend towards larger TVs, 21” CRT computer monitors have become the vehicle to deliver dramatic multi-media information into the office and home. Personal Local Area Networks, or PLANs developed, centered around the PC. PLANs in the home and office automatically synchronized and transferred appropriate data over broadband Internet connections between the home and office for the 25% of the working population telecommuting. In addition, PCs took on the role of a distributed and 24-hour computing resource, whose down time could be shared/leased with other machines to enable unfathomably-large calculations realized only by supercomputers before.

Broadband developed relatively quickly, seeing deployment primarily through the existing cable TV network as well as local fiber routed into businesses and homes. On the other hand, the vision of server-based IT pushed by GE’s Sun Division, did not come to pass not only due to security concerns, but also because the fact that it was much more efficient to transfer small programs over networks than the immense quantities of data they produce. The promise of a “paperless society,” trumpteted for more than twenty years, remained ten years off; the unassailable quality of print on paper and continued decreases in the cost of printers, combined with an increase in their quality and printing rate, meant that many office workers now have a 30ppm, $100 personal printer. High-performance UPSs maintain the reliability of the world’s computer and telecommunications networks, and UPSs developed for each home as well, as part of the general utility service delivered to each home. After overcoming information exchange format problems experienced in the early days of e-commerce, e-commerce prospers today, with PC computing power and high-bandwidth networks allowing information agents to truly do their masters’ bidding. Looking back, Senator Gates (I-WA) notes that government action, or more succinctly inaction, played a crucial role in allowing the nation to “ride the wave of IT-generated productivity and economic growth”.

7.1.3 The Greening of IT

In response to growing evidence of global climate change, the European Union and Japan capped CO_2 emissions, independent of the United States. Their portfolio of policies to reduce CO_2 production from electricity generation included explicit limits on the energy consumption by IT devices, the fastest-growing component of electricity use in the EU. The first steps mandated power management features for all devices limit “leaking” power from devices (i.e., energy consumed by computers and other equipment when not in use or even turned off). Soon after, the European Parliament converted the voluntary portions of the Energie 2000 Program into mandatory specifications for the maximum energy consumption of devices in different modes: computers, monitors, and “graphic reproduction devices”. The United States balked at these measures, but the Chinese and Taiwanese manufacturers quickly responded to the challenge. Eventually, U.S. manufacturers followed suit, wanting to play in the EU market, whose 28 members comprise the largest common market in the world. Consequently, the U.S. *de facto* adopted the same standards as the EU, as the economics of volume production in the horrifically-competitive marketplace compelled U.S. manufacturers to produce a common offering. Display manufacturers were particularly hard hit by the display regulations, which levied taxes on monitors drawing more than 35W, essentially limiting the production of CRT monitors larger than 13” to niche applications and effectively establishing LCD technology at the standard. Today, higher-quality organic LED displays have taken a 17% share of the display market.

Meanwhile, EU and Japanese investments in “green” IT, which had risen seven-fold over the past decade, began to bear fruit. Wireless telephony, always more popular in Japan and Europe than in the U.S., offered unexpected capabilities and even office tool functionality, driven by high-performance chips, widespread high-bandwidth fiber optic and wireless network, and organic LED displays. However, the miniscule screens simply could not offer a viable interface for all but the simplest applications. Addressing this shortcoming, Sony produced the first commercial Personal Electronic Tableaus (PETs), a foldable 20cm high by 15cm wide by 1cm thick device with a crisp, high-resolution display, that could download and store a variety of information from the surrounding networks. PETs regularly synchronize with PLANs, storing duplicates of all information on LANs. Integration of effective (99%+ accurate) and intelligent voice recognition software increased PETs efficacy, as did the ability to electronically “mark-up” up documents via voice or electronic stylus. Echoing the rapid ascent of NTT’s 3G wireless service first deployed in 2001, PETs became commonplace in offices circa 2008. Presently, the quality of PET displays has approached that of printed paper and bond paper consumption appears to be leveling off. Traditional books remained popular, however, as interminable copyright and logistical conflicts impeded the distribution of media content electronically. Desktop PCs, now considered the inefficient and cumbersome dinosaurs of a past era, continue to solider on in applications where their dense computing power can overcome their lack of mobility.

7.2 Future Scenarios and Energy Consumption

Figure 7-1 presents the projected total AECs for the key equipment types (see Table 7-1) under the different scenarios. All scenarios assume the same rate of economic growth; in general, appreciable increases or decreases in GDP growth rates can have a substantial impact upon device stocks and, hence, energy consumption.

Table 7-1: Key Equipment Types Included in Scenarios

Key Equipment Types
Personal Computers and Server Computers (excepting Workstations)
Monitors and General Displays
Laser and Inkjet Printers
Copy Machines
Telephone Network Equipment (excepting Wireless Phones)
Computer Network Equipment (excepting CMTS, RAS/Modem
UPS
New Devices included in Future Scenarios

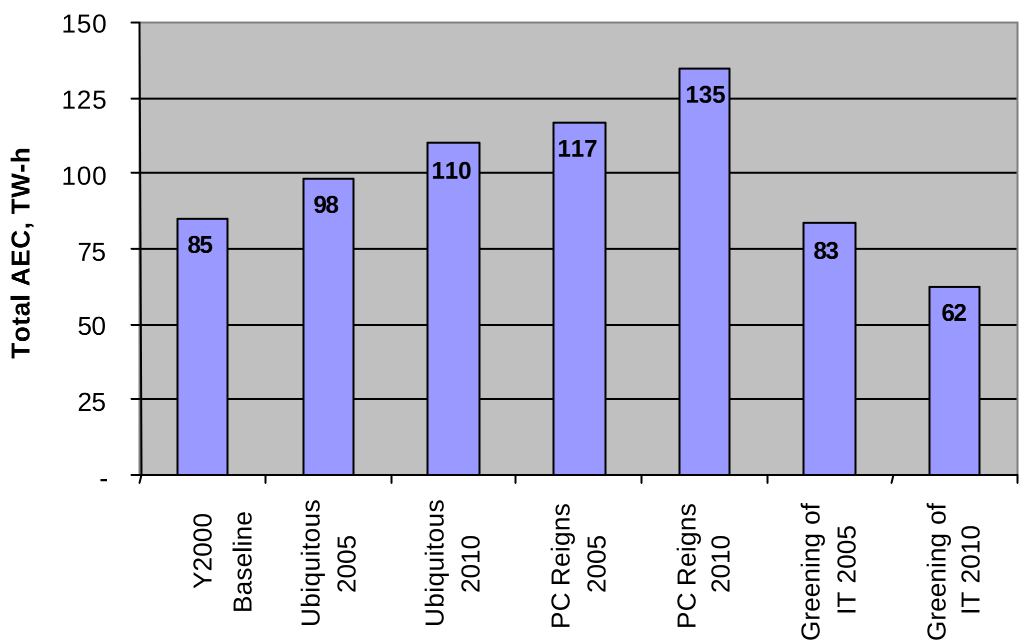

Figure 7-1: Scenario AEC Estimates (*Only* for Key Equipment Types)

Figure 7-2 compares the compound annual growth rates (CAGRs) of office and telecommunications equipment AEC for the different scenarios.

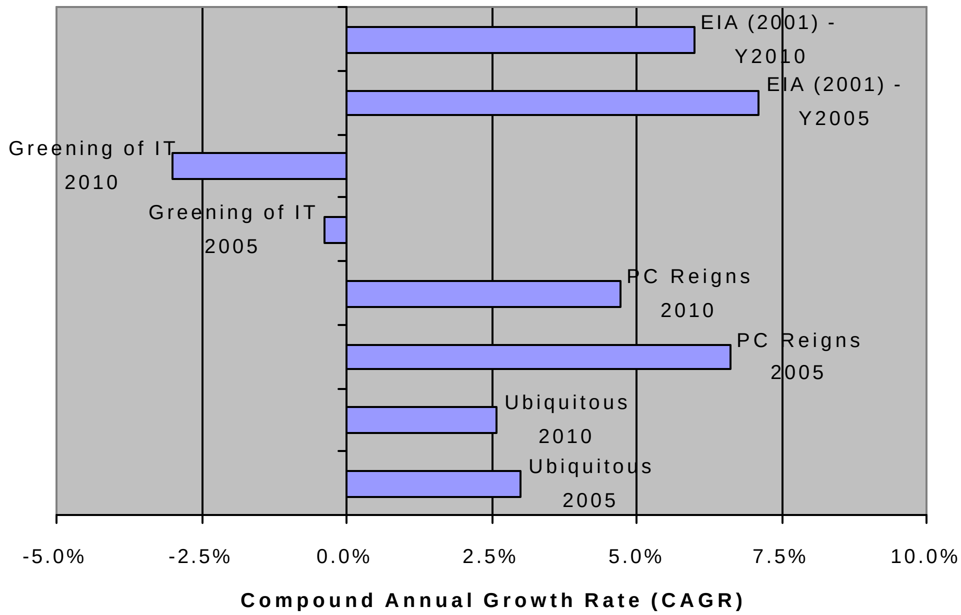

Figure 7-2: Office and Telecommunications Equipment AEC Compound Annual Growth Rates, by Scenario (*Only* for Key Equipment Types)

Figures 7-3 through 7-9 compare projected AECs for each major equipment type. The AEC projections follow the spirit of the scenarios put forth in the prior section but *do not precisely follow the text of each scenario*. This reflects the goal of the scenario approach: to develop a vision of how the future could be, and subsequently flush out the details. Tables F-1, F-2, and F-3 explain the AEC projections in greater detail (see Appendix F).

The range of electricity consumption growth rates (CAGRs) projected under the different scenarios vary greatly, showing very aggressive growth under the "PC Reigns" scenario and decreases in the "Greening of IT" scenario (see Figure 7-2). These results clearly illustrate that the application of new technologies in equipment types that consume a significant portion of energy today (e.g., LCD monitors, high- or low-power microprocessors) will be the major determinant of future electricity consumption. Future power management (i.e., ENERGY STAR®-enabled) rates and device stock levels (e.g., fiber-optic terminal and cell site equipment deployment) will also exert a strong influence on the evolution of office and telecommunications AEC.

For sake of comparison, the EIA (2001b) data permit calculation of future projected growth rates for office equipment - but not telecom and computer network equipment - for the period from Y2000 to Y2005 and Y2010. Both EIA projections exceed the growth rates resulting from *all* of the scenarios, although the "PC Reigns" Y2005 case approaches the EIA rate over that period. The wide range of future AEC growth rates generated by the scenarios suggests that the EIA should consider a broad range of "high" and "low" cases when developing future AEC projections for PCs and office equipment.

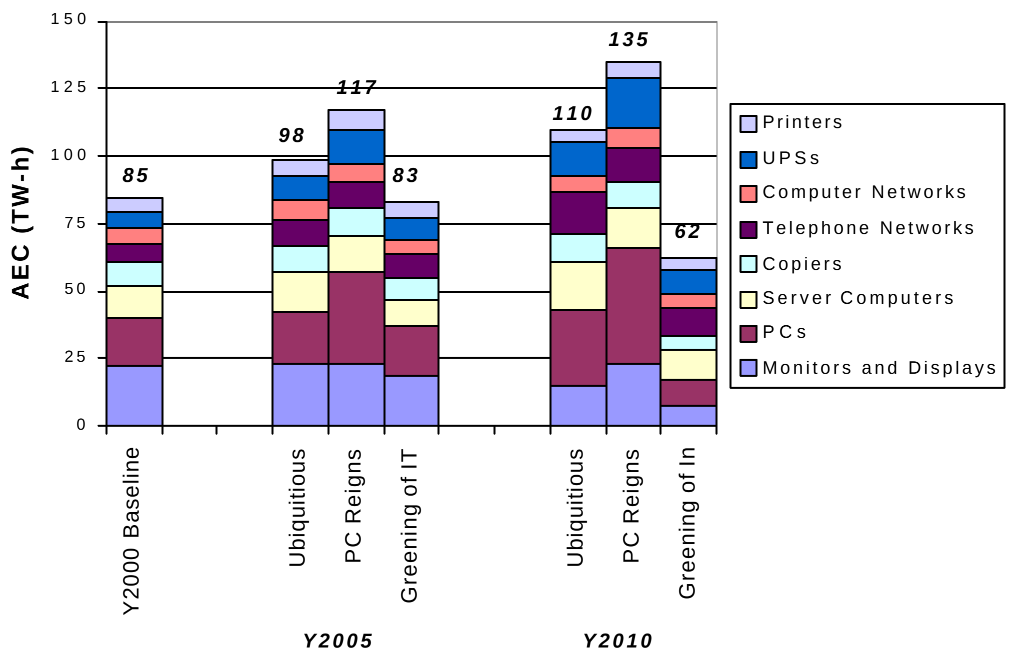

Figure 7-3: Key Equipment Type AEC Projections, by Scenario and Year

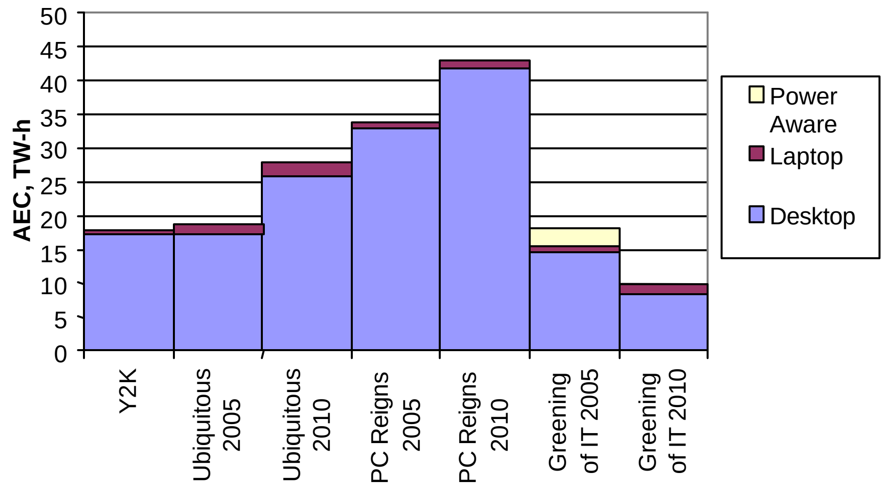

Figure 7-4: Personal Computer AEC Projections, By Scenario and Device Type

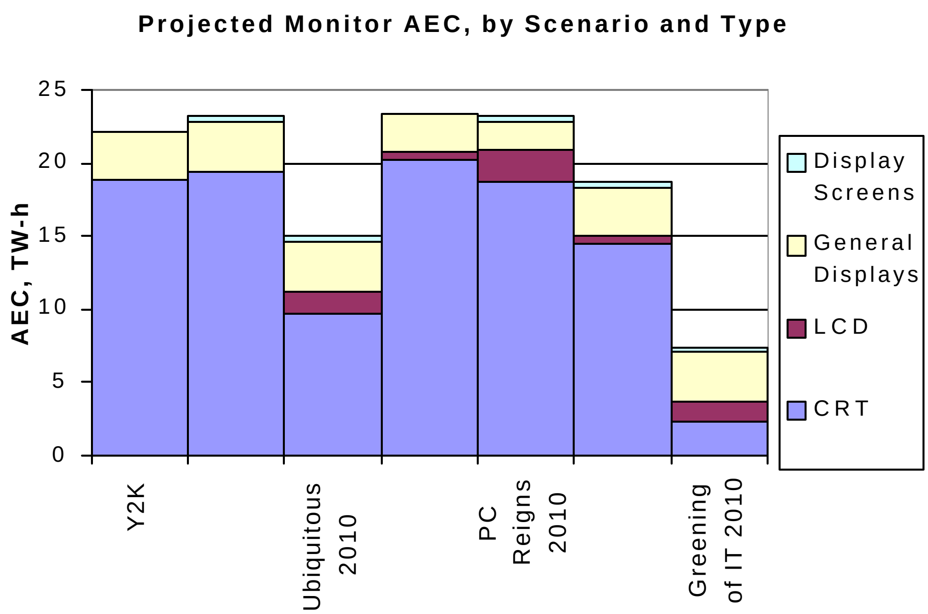

Figure 7-5: Monitor AEC Projections, By Scenario and Device Type

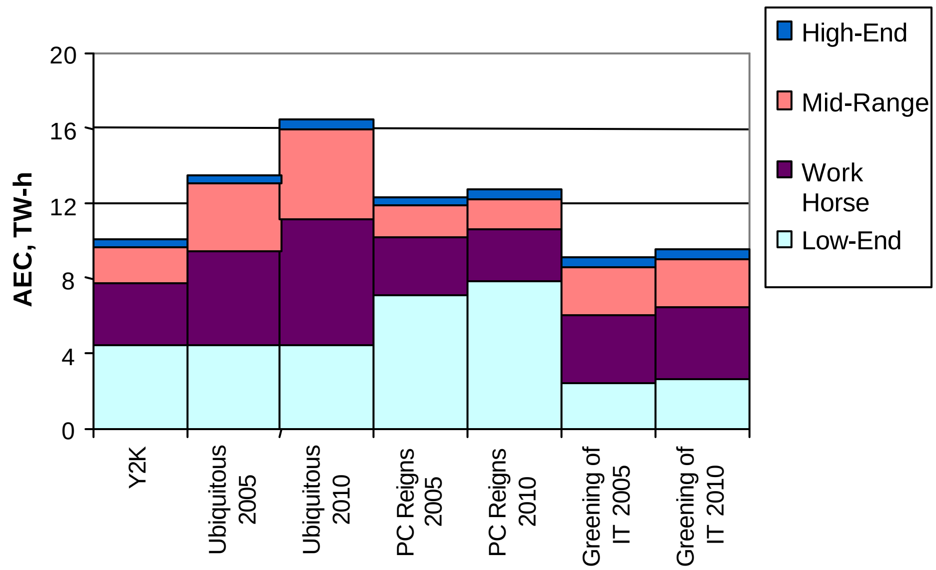

Figure 7-6: Server Computer AEC Projections, By Scenario and Device Type

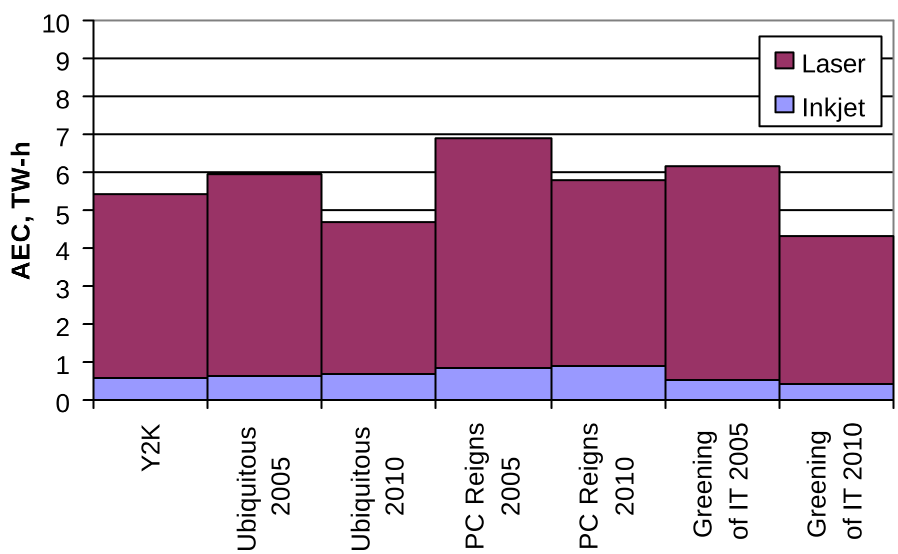

Figure 7-7: Printer AEC Projections, By Scenario and Device Type

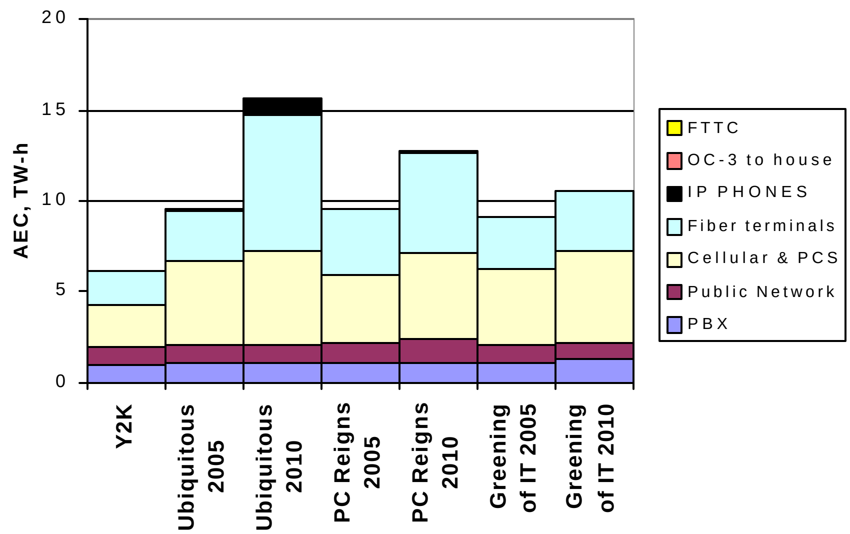

Figure 7-8: Telephone Network AEC Projections, By Scenario and Device Type

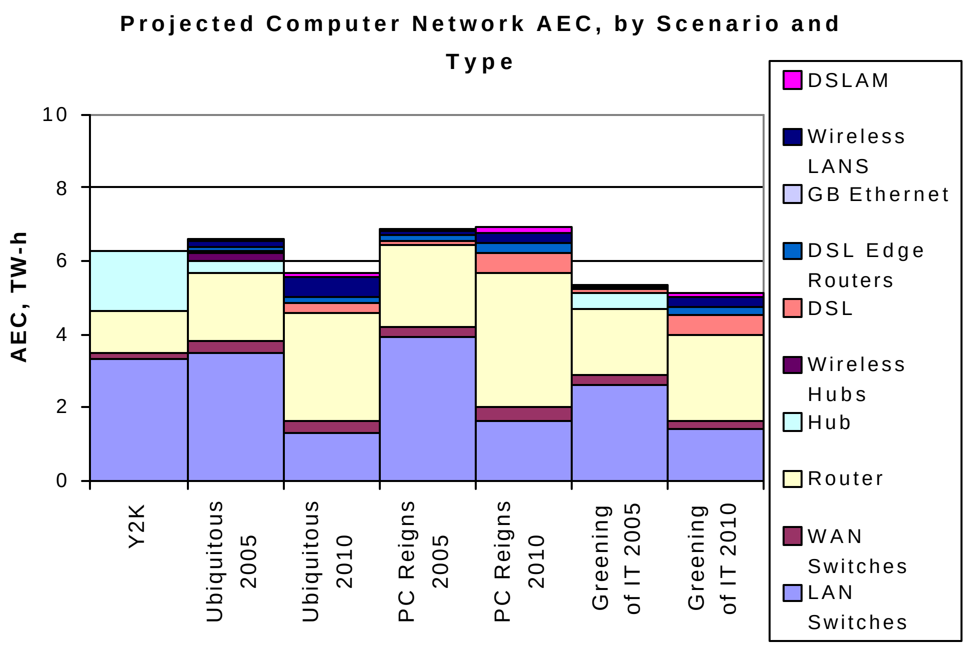

Figure 7-9: Computer Network AEC Projections, By Scenario and Device Type

7.3 Key Drivers and Technologies by Equipment Type

Numerous factors will strongly influence the future energy consumption by each equipment type. Some of the key economic, societal, and political drivers are discussed below.

Growth of e-Commerce: How long will it be before a significant portion of business purchasing moves to the Internet? This has major implications for the quantity of data moving through the Internet and the power to support the necessary infrastructure. The growth of personal e-commerce, which has encountered profitability barriers in many instances, will have a smaller influence upon direct energy consumption in the commercial sector.

Mobile Internet Access: Will companies be able to afford the estimated global cost of approximately $300 billion purchase licenses and build infrastructure required for 3G mobile telephony (Economist Technology Quarterly, 2000B). When will 2.5G and 3G arrive, promising much faster and superior access to Internet content and services, and will people adopt these services in large numbers? This trend has ramifications for the continued growth of mobile base stations, as well as the computer network infrastructure. Will "m-commerce" (mobile-commerce) take off?

Convergence of Data and Voice Networks: To a sizeable extent, this has already occurred, as fiber optic (transmission) networks carry data.

Ubiquitous Computing: To what degree will it happen and how fast? In theory, a variety of devices could access the net, intermittently, to communicate information to network for control purposes and/or diagnostics (e.g. in a smart building). However, cost and security concerns (e.g., how to control access to control networked devices – does each device need its own password?) can appear daunting. Will personal local area networks (PLANs), which synchronize information between fixed computers and portable devices, become widespread in the home and in the office?

Growth of Broadband Internet Access: Large-scale adoption of broadband Internet access (DSL, cable modem, fiber-to-the-curb or -home [FTTC, FTTH]) would greatly increase the data flow through computer and data/voice networks (e.g. by enabling the widespread distribution of video via the Internet). As of late Y2000, broadband roll-out ran at about one-half expected levels and promised to slow further due to a decreased access to capital experienced by most providers (Basel, 2001).

Where are Data Stored?: Sun Microsystems is a primary proponent of a model where data and applications are stored and run not on PCs but on remote servers. Data security and high-speed access issues, as much as the ever-decreasing cost of PCs, have worked against this approach to computing since the rise of the PC. If the server-centric paradigm ever comes to be, it could radically alter the device landscape, greatly increasing the stock of server computers and computer network equipment. How much will redundant data storage grow?

Device Reliability: As society becomes increasingly more dependent upon information technology, the consequences and costs of equipment failure will increase. How will electronic devices – which are particularly sensitive to power quality – increase their up-time in the future? Some possible solutions include greater UPS usage, increased redundancy, local (distributed) power generation, and more robust electronics/microprocessors.

Miniaturization: Will device functionality migrate to smaller, portable devices? The increased sales of smart handheld devices and laptop computers suggest that it may, possibly with major energy consumption implications. If the devices supplant existing devices, the low-power battery-powered portable devices could dramatically reduce energy consumption. On the other hand, if they supplement, they will increase demands upon mobile and computer networks.

Device Power Management Rates: The voluntary ENERGY STAR® program, launched in 1993 by the DOE and EPA, reduces the power consumption of qualified computers and peripherals by powering down devices when not in use. Although most office equipment is ENERGY STAR® compliant, actual enabled rates are far lower for most equipment types (see Section 5). Will ENERGY STAR® enabled rates increase in the future (e.g., through programs such as LBNL's Program to Standardizing Power Management Controls[131]), and expand to server computers?

What New Devices and/or Applications Will Arise?: What new devices and applications will arise that have a major impact upon energy consumption by office and telecommunications equipment (i.e., what will be the next Internet)? What will the future hold for portable electronic tablets, enabled by superior voice recognition software? For example, widespread use of very data intensive real-time video, such as effective real-time 3-D rendering of a videoconference (tele-immersion), requires "literally dozens of … processors … at each site to keep up with the demands of tele-immersion" (Lanier, 2001), with clear ramifications for energy consumption. "The Grid,[132]" essentially a form of widespread distributed computing that makes use of the latent computational power of desktop computers while not actively used, is another application with the potential to increase dramatically desktop computer and computer network energy consumption. How will ubiquitous will embedded

[131] See: http://eetd.LBL.gov/EA/Controls/ .

[132] "The Grid" concept parcels out portions of very large computation problems to many (up to thousands) remote computers and accesses their (combined) immense volume of computational power to solve much of the problem on the remote computers. Typically, the computers guiding the calculations only access the remote computers when the remote computers would otherwise lie fallow, e.g., at night or on weekends. If adopted as a computational paradigm on a large scale, the extended hours of operation would dramatically increase the energy consumption of commercial and non-residential computers. The increased data flow also would likely augment network equipment bandwidth and power demands. The Economist Technology Quarterly (2001) discusses the opportunities and challenges of "The Grid" concept.

processors become in equipment currently not drawing power and how much energy will these "smart" devices consume?

In contrast to the broader trends discussed above, technological trends tend to be more specific to equipment types.

PCs*:* Will Moore's law continue into the future or will the cost of the chip fabrication plants waylay it? How will thermal engineers cope with the projected increase in power density (Azar, 2000)? Adaptable chip architectures, such as Transmeta's "Crusoe" chip (Technology Review, 2000) or the "raw" chip architecture posited by Agarwal (1999), could increase chip efficiencies several fold while maintaining acceptable power densities. Research into new materials, e.g., carbon nanotube-based microprocessors, hold promise for decreased electrical resistance and lower power densities. Or will miniature refrigeration cycles cool the chips of the future? Will low-power laptops continue to decrease in price to claim a greater portion of the market from desktop PCs – the Economist (2000c) foresees this occurring circa 2003. Will organizations begin using the immense quantities of processing power of their personal computers lying fallow at night to run very large programs, distributed over many machines (Economist, 2000a)?

Monitors and Displays: LCDs consume less than 1/3rd of the energy of a similarly-sized CRT. Will their prices continue to decline and, combined with their small physical profile, enable them to capture a significant portion of the monitor and display market? When might organic light-emitting diodes, which promise superior image quality and one-half the manufacturing cost of LCDs – and could consume about 1/3rd the power of LCDs (Economist, 2001b; Semenza, 2001b) – penetrate the monitor market? Will laptops replace desktop PCs in greater numbers, possibly decreasing the stock of monitors in commercial buildings? Will e-paper[133] ever become a reality, not only a replacement for conventional paper but as a living interface in stores, office spaces (e.g., bulletin/cork boards), etc.?

Server Computers: The growth of Internet traffic will have a dramatic impact upon server computers and accompanying data storage demand. Companies have begun developing low-power servers tailored for web serving applications (Hipp, 2001). Will this trend, in part driven by data center cooling issues, continue? The research of Gubler and Peters (2000) suggests that low-, mid-, and workhorse-class servers all offer substantial opportunities for energy savings via power management – will this occur? At the high end, will the renaissance of the "enterprise server" (mainframe) continue, replacing large quantities of low-end machines with dynamically-allocated flexible memory and I/O? How will mainframes proliferate in new industries (e.g., biotechnology)?

[133] Soares (2001) briefly reviews the history and possible future of e-paper development.

Copy Machines: Two companies, Ricoh and Canon, have built lower-powered copy machines that fulfill the lower-power requirements of the International Energy Agency's (IEA) "Copier of the Future" program. Will such products capture significant market in large quantities? Oki, a Japanese company, has developed a two-layer (encapsulated) toner that they claim reduces the power consumption for fixing by about 30% (Ishihara et al., 1998). Furthermore, reducing the required temperature for fusing the toner to the paper decreases the energy used to keep the fuser roll warm, reducing stand-by losses. Will this (or similar) technologies capture significant market share? How popular will color copying become? Any move towards a paperless office would reduce energy consumption by copiers. The potential exists for copy machines and printers to merge, particularly for lower-end devices, possibly resulting in decreased stock of copiers and printers.

Printers: As noted above, copier manufacturers have begun to develop lower-temperature toners – how common will they become in laser printers? Will increased demand for color laser printers materialize, increase energy consumption? Might inkjet printers' print quality and speed continue to improve, increasing their deployment in traditional office applications? Would that increase (by increasing the number of devices) or decrease energy consumption (lower stand-by power levels)?

Computer Network Equipment: Computer network equipment have seen dramatic increases in data transfer rates, which tends to increase the power draw of all devices while superior and smaller electronics push down device power draw per megabit of data transfer - which trend will win out?

Telephone Networks: How great will the demand for mobile Internet access be and when will the services arrive in the U.S., particularly 3G? Standards cap the power of the transmitters; how long will 2G and 3G transmitters (which are distinct) coincide? Will Internet protocol (IP) telephony seize a significant portion of the voice traffic? When might fiber-to-the-curb/home (FTTC/FTTH) – and the millions of neighborhood fiber terminal to support FTTC/FTTH - become commonplace?

UPSs: The demand for high power quality to ensure reliability will drive future UPS unit growth[134]. A dramatic increase in high-power quality demand and its infrastructure (e.g., from a few billion dollars per annum in Y2000 to $50 billion/year by 2005 and to $100 billion/year by 2010, as posited by Yeager and Stahlkopf [2000]), would dramatically increase the stock of UPSs. What portion of the market will continue to use inefficient "double-conversion" technology? How much will distributed generation displace UPS functions?

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[134] The Consortium for Electric Infrastructure to Support a Digital Society (CEIDS) was formed in 2001 to improve electricity quality via electricity grid improvement, local electricity generation and storage, and built-in digital equipment protection.

Tables 7-2, 7-3, and 7-4 present the key trends that we believe would impact each key equipment type under each scenario.

In the "Ubiquitous Computing" scenario, people want to – and can – access Internet content from almost anywhere. The key trends and drivers explain how this central fact plays out for different equipment types.

Table 7-2: Ubiquitous Computing Scenario - Key Trends by Equipment Type

Equipment Type	Key Trends
PCs	• Emphasis on portability drives laptop PC growth, at expense of desktop PCs • Semi-portable PC (lunchbox-size) returns to market • Desktop computers left on more often to provide connectivity ("always on")
Server Computers	• Greater workhorse and mid-range server growth to serve greater quantity of network access points • High-end growth to flexibly and reliably manage data growth
Monitors and Displays	• Laptop PC growth drives reduction in CRT stock • Emphasis upon portability limits growth in CRT size
Copiers	• Economics drive merger of copiers and laser printers, notably lower-speed devices
Printers	• Low-end laser printers assimilated into multi-function devices (with copiers, facsimile machines, scanners) for economic reasons • Many mid-range laser printers assimilated into multi-function devices (under copiers) • Paper consumption in offices growth unabated
Telephony Network Equipment	• Rapid 3G wireless roll-out, proliferation of wireless towers • Continued growth in fiber optic (FO) terminals for additional network backbone access points • Soaring local network data flows accelerate FO terminal bandwidth growth • Rise of fiber-to-the-curb (FTTC) and fiber-to-the-home (FTTH), residences and businesses
Computer Network Equipment	• More routers to handle increased network access • Wireless "hubs" arise to meet demand for portable device network access • High-bandwidth LANs, leading to fiber optics networks in larger office buildings • Smarter, more capable routers manage bandwidth growth and provide better security, supplanting passive hubs
UPSs	• Power reliability increases to support devices providing ubiquitous connectivity • Distributed power generation rise slows growth of UPSs • Portable and semi-portable devices have batteries

The “PC Reigns” scenario has at its heart the continued dominance of a powerful desktop PC for personal computing and Internet access, both at home and at work. Table 7-3 describes how a desktop-centric world would impact other types of office and telecommunications equipment.

Table 7-3: PC Reigns Scenario - Key Trends by Equipment Type

Equipment Type	Key Trends and Drivers
PCs	• Desktop PC remains the primary computing and Internet access device • Microprocessor power growth continues, reflecting value of performance in primary computing device • “Always On” desktop PCs proliferate
Server Computers	• Dramatic increase in broadband access and data intensive content drives strong growth in low-end Internet servers • Functionality and data storage moves to vast desktop PC hard drives away workhorse and mid-range servers
Monitors and Displays	• Larger CRT displays favored to enhance desktop-centric experience • LCDs become widespread to save valued desktop real estate
Copiers	• Economics dictate that copiers assimilate a large portion of lower-end laser printers into multi-function devices • Higher-end machines remain distinct
Printers	• Personal inkjet and laser printers in offices become popular part of desktop-centric personal office suites, driven by continued cost reductions, desire for color, and print quality gains
Telephony Network Equipment	• Broadband becomes widespread, first via cable modem and DSL, ultimately via fiber-to-the-home (FTTH) and fiber-to-the-curb (FTTC) • Dramatic increase in data flows accelerates fiber optic connectivity (number and bandwidth of terminals) • Low-speed wireless Internet access (e.g., 3G) faces low interest from desktop-centric world
Computer Network Equipment	• Emphasis on LAN and router bandwidth to effectively deliver large quantities of data • Smarter, more capable routers manage bandwidth growth and provide better security, supplanting passive hubs
UPSs	• Desktop-centric world drives demand for stand-by UPSs • Rapid growth of larger UPSs to support data center servers • Closer integration between people and desktop PCs increases cost of down-time, fueling growth in UPSs for servers

The "Greening of IT" scenario features device efficiency, while market forces shape the installed base (stock) of equipment types (Table 7-4). Consequently, power-aware design becomes the rule for a growing stock of office and telecommunications equipment.

Table 7-4: Greening of IT Scenario - Key Trends and Drivers by Equipment Type

Equipment Type	Key Trends
PCs	• Desktop PCs predominate, many with power-aware designs • Power management (PM) widely enabled
Server Computers	• Data center cooling issues and power economics help drive precipitous decrease in low-end server power draw and rise of PM features • Flexibility and high capability-to-power draw ratio lead to resurgence of high-end servers
Monitors and Displays	• LCDs become the standard display, for power and space reasons
Copiers	• Lower-temperature fusing processes decrease stand-by power consumption and enable more frequent "sleep" mode operation • Paper consumption plateaus circa 2005 and begins to decrease, supplanted by high-quality displays and nascent bi-stable e-ink
Printers	• Faster and higher quality inkjet printers take much of low-end printer market • For economic reasons, a majority of lower-end laser printers merge with copiers in multi-function devices • Lower-temperature fusing processes decrease laser printer stand-by power • Paper consumption in offices levels off and begins to decrease
Telephony Network Equipment	• Market demands lead to continued growth in fiber terminals, wireless telephony, and broadband • Some improvement in terminal and wireless
Computer Network Equipment	• Push for efficiency results in much lower power consumption per bandwidth, with a moderate drop in potential (and a small drop in actual) throughput • Smarter, more capable routers manage bandwidth growth and provide better security, supplanting passive hubs
UPSs	• Improvement of device efficiency via migration away from double-conversion devices • Moderate stock growth as servers and data centers become more efficient

8 Indirect Impacts of Office and Telecommunications Equipment

Office and telecommunications equipment in commercial buildings directly impact energy consumption by the power they draw during operation. The hundreds of millions of devices also have several potential indirect impacts on energy consumption. On the building (as well as the national) level, they alter the energy consumption of heating and cooling systems, while on a local level they affect peak electricity demand. The energy used to manufacture the devices and the macroeconomic influences of information technology (IT) upon U.S. energy intensity, due to e-commerce and productivity changes, impact national energy consumption. The energy consumed to make the paper consumed by printers, copiers, and facsimile machines also increases national energy consumption. Beyond energy impacts, the disposal of tens of millions of obsolete office and telecommunications devices a year imposes an environmental burden upon landfills.

All of these issues embody significant complexity and a thorough analysis of each lies beyond the scope of this report. The following sections introduce and discuss the main issues surrounding each indirect impact of telecommunications and office equipment.

8.1 Air Conditioning and Heating

The magnitude of office and telecommunications in conditioned areas in commercial buildings has ramifications for the air conditioning loads imposed upon those buildings. Specifically, the electricity consumed by the equipment is equivalent to electric resistance heating. The precise impact of the equipment upon building loads varies greatly with the local climate as well as the type of building in question, thereby complicating quantification of the impact of the heat generated by the office equipment upon heating and cooling loads.

Building HVAC system designers typically take office equipment into account. Wilkins and Hosni (2000) report work by other authors who measured the power density of office equipment loads. They found that reported loads ranged from 0.44W/ft^2 to 1.08W/ft^2, with an average value of around 0.8W/ft^2. The highest power densities arose in areas with densely populated office spaces with one workstation and one monitor per person. Naturally, some spaces (such as computer rooms) can generate much higher local loads, as do the portions of data centers densely packed with servers and computer and telecommunications network equipment. Based on a number of sources (Goldsmith and Blazewicz, 2000; Mitchell-Jackson, 2001; Stein, 2001), the portions of data centers dedicated to servers and network equipment appear to draw somewhere between 20 and 60W/ft^2, with the actual values depending on equipment density and occupancy.

In a building, office equipment effectively lowers the outdoor balance temperature, above which the building requires air conditioning and below which the heating system operates. When it is warm outside, the office equipment generates an additional heat load which must be balanced by additional air conditioning, as well as additional fan ventilation energy required to introduce and remove the cooled air from the conditioned space. The additional fan energy, in turn, dissipates in the conditioned space, further increasing the cooling load[135]. Office buildings employ a variety of cooling equipment ranging from packaged rooftop units to large, central chillers (ADL, 2001). The cooling efficiency of these devices, including fan energy, varies appreciably with the weather conditions, equipment type, efficiency, and system design. Overall, the heat dissipated by the office equipment increases the cooling/ventilation system electricity demand by between 20% and 50% of the dissipated heat (i.e., a PC monitor dissipating 100W will incur another 20 to 50W in compressor and fan energy; the range reflects the wide range of equipment performance, as well as climatic influences on system efficiencies).

On cold days, the office and telecommunications equipment acts as electric resistance heating and displaces a portion of the heat that the building's heating system(s) would provide, generally one Btu of heating load per Btu dissipated by equipment[136]. Put this way, the heat dissipated by the equipment reduces heating loads, albeit inefficiently by supplanting the existing heating with inefficient resistant heating (see Table 8-1).

Table 8-1: Impact of Office and Telecom Equipment Upon Building Heating and Cooling Primary Energy Consumption

Heating System	Typical Seasonal Efficiency (from ADL, 2001)	Primary Energy Efficiency[137]
Packaged A/C	COP[138] ~2.1	0.65
Water-Cooled Chillers	COP ~ 3.8 to 4.3	1.17 to 1.35*
Electric Resistance Heating	~98%	0.31*
Heat Pump, Heat/Cool	COP ~ 2.1/2.0	0.65
Gas or Oil Furnace	73%	0.73*
*Does not include impact of fan energy		

[135] Except for exhaust fans, which dissipate energy outside of the building.

[136] Many commercial buildings have portions of the building that require cooling even during the heating season (e.g., the interior zones of office buildings), where the office equipment would continue to increase the cooling load.

[137] Assuming 10,958Btu of primary energy equals one kW-h of electrical output (BTS, 2001).

[138] The coefficient of performance (COP) reflects the amount of heat or cooling provided per unit of energy input into the heat pump.

The net impact of office and telecommunications equipment electricity consumption upon heating and cooling loads depends upon the net balance of cooling and heating primary energy consumption, averaged over the entire population of buildings and climates of the U.S. For instance, greater cooling energy consumption indicates that office equipment would tend to operate more often during cooling periods than during heating periods, and would thus increase cooling loads more than it displaces heating loads. In addition, the relative performance of heating and cooling equipment in primary energy terms determines the relative magnitude of any *marginal* load upon net heating or cooling. Excepting water-cooled chillers, most heating and cooling equipment have similar primary energy efficiencies (Table 8-1), meaning that any additional heat dissipation will not have a dramatic impact upon net primary HVAC energy consumption.

Lighting and office equipment have similar impacts upon HVAC energy consumption, as they both represent additional building loads beyond shell and outside air loads. Sezgen and Koomey (1998) studied the impact of lighting loads upon building heating and cooling energy consumption for eleven different building types, of "new" and "existing" vintages, in five distinct climates. They found that lighting (and, hence, office equipment) heat dissipation had approximately no net impact upon HVAC primary energy consumption. A recent study of HVAC energy consumption based upon the CBECS 1995 survey data (ADL, 2001) supports this conclusion, showing similar amounts of cooling and heating primary energy consumption (2.0 and 1.8 quads, respectively, including associated parasitic energy) in commercial buildings. This, combined with the rough primary energy equivalence between heating and cooling systems shown in Table 8-1, supports the general conclusion of Sezgen and Koomey (1998).

There exists one major caveat: the majority of office and telecommunications equipment operates in office buildings[139] which, on a national basis, consume appreciably more cooling energy than heating energy (see Table 8-2).

[139] According to Boedecker (2001), the EIA classifies data centers, which have extremely high densities of server computers, data storage devices, and computer and telecom network equipment, as office buildings.

Table 8-2: Office Building Heating and Cooling HVAC Energy Consumption (from ADL, 2001)

Building Type	Mode	Primary Energy Consumption (no parasitics)	Primary Energy Consumption (with parasitics[140])	Net Cooling Energy, % Difference[141], (with parasitics)
Non - Office	Cooling	0.99	1.1	+16%
	Heating	1.5	1.5	
Office	Cooling	0.37	0.41	-21%
	Heating	0.25	0.26	

Averaged over the U.S., office buildings demand cooling substantially more often than heating. Consequently, the heat dissipated by office and telecommunications equipment likely increases HVAC primary energy consumption in office buildings by roughly 20% of the amount of energy consumed by the equipment. On the other hand, equipment heat dissipation in non-office reduces HVAC energy consumption by about 15% of the amount of energy consumed by the equipment.

Ultimately, the relative density of office equipment in office (and other) buildings determines the net HVAC impact. To study this effect, we created a very simple model of office equipment impact upon HVAC energy consumption by assigning relative portions office equipment to office and non-office buildings[142], using the heating-cooling-HVAC primary energy consumption ratios values from Table 8-2 and Sezgen and Koomey[143] (1998) (see Figure 8-1).

[140] From ADL (1999): Cooling Parasitics - Condenser fans, cooling tower fans, condenser water pumps, chilled water pumps; Heating Parasitics - Heating water pumps.

[141] Equals: (Cooling – Heating) / (Heating + Cooling)

[142] This does not take into account variations in office equipment densities between different types of non-office buildings

[143] We used the site energy data of Sezgen and Koomey (1998), based on Y1989 CBECS data for "existing" office buildings, in conjunction withY1995 CBECS floor space data for these calculations.

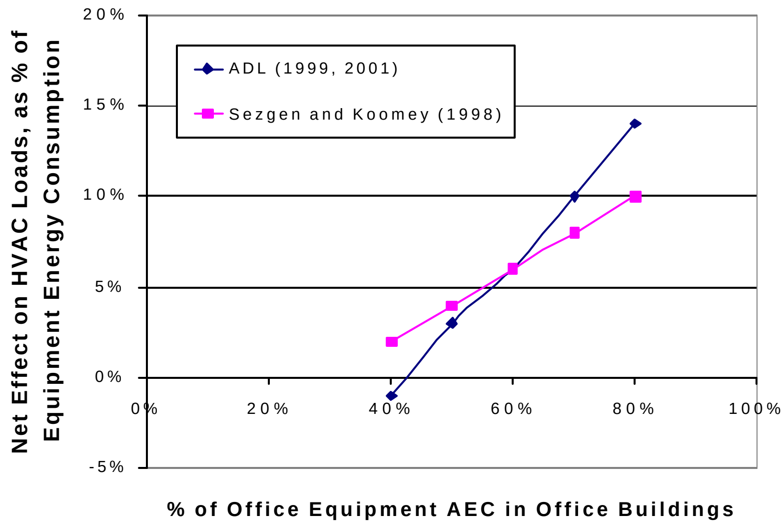

Figure 8-1: Approximate Impact of Office Equipment Density on HVAC Energy Consumption

When 50% of office equipment energy consumption occurs in office buildings, both data sources suggest that office equipment energy consumption results in a very small increase in commercial building HVAC energy consumption. In practice, the percentage of all office equipment operating in office buildings almost assuredly exceeds 50%[144], indicating that office equipment most likely generates a net increase in commercial building HVAC primary energy consumption. A more thorough analysis would take into account factors such as actual office equipment densities in different building types and coincidence between office equipment usage and heating/cooling demand over the course of each day.

8.2 Peak Power Impact

The power draw of office and telecommunications equipment during the periods of peak draw (i.e., typically mid-afternoon on hot, summer days, when air conditioning usage in commercial buildings peaks) makes three distinct contributions to peak power demand. The first two, the direct power draw of the equipment and the power draw of the additional air conditioning required to cool the heat dissipated by the equipment, are described in Sections 5 and Section 8.1. The third, additional power

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[144] EIA (1998) estimated that in Y1995, 49% of PCs found in commercial buildings were in office buildings. The percentage of printers, copiers, and servers is undoubtedly higher.

demand resulting from low equipment power factors, increases power demand at the source and building levels.

The usage calculations included in this study reveal that power draw varies dramatically with usage mode and that most office equipment spends a significant amount of time in all modes – active, stand-by, suspend, and off – over the course of a week. Thus, the operating mode during the peak period plays a decisive role in determining the peak power impact. Generally, a large portion of office equipment will be in use or ready for use (that is, in active or standby mode) during this period. Wilkins and McGaffin (1994) measured the diversity factor of office equipment loads in a ~25,000 ft^2 office space. The diversity factor equals the ratio of maximum measured power draw of all of the office equipment in an office "zone" to the sum of the maximum measured power draw of each piece of equipment. They found that the diversity factor varied greatly, from 0.22 to 0.98, depending upon the type of equipment in a given space[145], with an average value of 46%. The wide range of diversity factors confounds precise estimation of the impact of office equipment upon peak power demand.

On the other hand, most server computers and computer network equipment operate around the clock, with only small variations in their power draw. Consequently, their power draw approximately equals their "active" power mode draw during the peak load period. Overall, based upon the device usage patterns outlined in Section 5 and Appendix G, office and telecommunications equipment has a ratio of peak-to-(annual) average power draw of approximately between 1.2 to 1.5. Thus, the equipment is less "peaky" than office buildings as a whole (ratio of 1.8; from Maisy, 2001), presumably because of large increases in HVAC power draw during peak demand periods.

Power factors[146] do not directly increase energy consumption per se, but they do increase the required output of a power plant. MACEBUR (1998) finds that most office equipment have power factors of about 0.6, primarily due to lower-quality power supplies. In practical terms, this means that the power source must generate 1.67 times more power than actually demanded by the low power factor equipment, increasing the effective electricity demand as well as electricity transmission and distribution losses. In sum, the low power factors of office equipment exacerbate peak power problems.

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[145] The presence of devices with very high transient peak loads (i.e., laser printers and copiers) tends to depress the diversity factor.

[146] A power factor equals the ratio of the delivered ("real") power to the apparent power. A power factor of less than one arises when electronics in a device cause the current and voltage to be out of phase. As a result, to achieve the "real" power level, the apparent power (i.e., the RMS of the product of the voltage and current) must increase because their peaks do not coincide. The device does not consume additional power, but the power plant must generate the higher levels of apparent power, which also increases transmission and distribution losses.

Taking into account all of these factors, on average, office and telecommunications equipment appears to increase the total peak power demand in any given part of the country by on the order of 3 to 4%[147]. This is not inconsistent with the peak demand breakdown for New Jersey developed by Xenergy (1999; data plotted in Nadel et al., 2000) that estimates that *all* commercial building miscellaneous end-uses[148] account for 9.6% of utility peak demand.

However, more study is required to calculate the actual peak load impact of office and telecommunications on commercial building peak electricity demand, particularly to model actual peak electricity demand and to capture differences between building types. For instance, buildings with very high densities of office equipment, such as office buildings, will encounter much larger increases in peak electricity demand from the equipment than buildings with lower densities (e.g., warehouses).

8.3 Manufacture of Office and Telecommunications Equipment

The manufacture of office and telecommunications equipment consumes an appreciable amount of energy and has several environmental impacts, including the release of greenhouse gases, waste materials (hazardous and non-hazardous), and the consumption of water. The Carnegie Mellon University Green Design Initiative (2001) developed a commodity input-output model of the U.S. economy based upon 1992 and 1997 U.S. Department of Commerce models and data which enabled life cycle analysis of the impact of the production of different equipment or materials. It is important to note that their model includes not just the energy and resources directly consumed in the manufacture of the devices, but also the resources consumed throughout the entire supply chain. For example, as applied to a CRT monitor, the model includes not only the energy consumed to manufacture the tube, housing, and electronics, but also the energy expended to extract and process the resources (e.g., lead, other metals, fossil fuels for electricity, etc.). Their model yielded the approximate energy and environmental impact for all computers and office equipment produced exhibited in 1997 (see Table 8-3).

[147]This assumes that office and telecommunications equipment has a "peakiness" (i.e., ratio of peak power demand to annual average demand) of 1.25, requires additional cooling and ventilation electricity consumption equal to 50% of device electricity consumption, and has an average equipment power factor of 0.7. Together, these factors yield ~25GW of peak power demand relative to an expected approximate "national net demand" of ~675GW in July of 2001 (NERC, 2001), where national net demand equals the sum of the expected peak demands in the different geographical regions of the U.S.

[148] Xenergy (1999, as shown in Nadel et al. [2000]) breaks down commercial sector peak demand into "HVAC", "Lighting", "Miscellaneous" and "Refrigeration", which account for 25%, 16.7%, 9.6% and 1.9% of total summer peak demand in New Jersey, respectively. Thus, the "Miscellaneous" category includes all end-uses besides HVAC, lighting, and refrigeration, including office and telecommunication equipment, cooking, water heating, elevators, etc.

Table 8-3: Approximate Impact of Manufacturing Computers and Office Equipment in 1997 (from Carnegie Mellon University Green Design Initiative [2001] and Kuhlbach and Planting [2001]).

Impact Metric	Quantitative Impact
Energy Consumed, quads	0.79
Electricity Consumed, TW-h	43
GHG Emissions (million metric Tons, CO_2 equivalent)	57
Hazardous Waste Generated (RCRA, million metric tons)	3.8
Water Used (billion gallons)	249

It appears that energy consumed throughout the supply chain to produce office and telecommunications equipment in the U.S. in 1997 is of the same order as the energy consumption by the entire stock in a single year. This statement comes with several caveats that could increase or decrease the energy impact of office and telecommunications equipment production. For example, the output estimate includes *all* computer equipment, not just that used in commercial buildings; although a majority of equipment (in dollar terms) certainly does flow to the commercial stock, this effect would decrease the impact. Presumably, manufacturing efficiencies have improved since 1997,which could reduce or actually increase the impact of production, depending upon gains in environmental efficiency (energy per $ of output) relative to improvements in economic efficiency (number of devices per $ of output)[149]. On the other hand, device shipment levels (both in number of units and dollar terms; see Section 5.1) have grown appreciably since 1997, increasing the sector output and energy consumption. More importantly, the ~0.8 quad estimate does not reflect the embodied energy of many key equipment types considered in Section 5, most notably computer network equipment, telephone network equipment, and UPSs. Undoubtedly, inclusion of these devices would substantially increase the embodied energy estimate.

It is important to iterate that the manufacturing energy consumption estimate includes the energy consumed to produce the components traced all of the way through the supply chain (i.e., to the raw resource level). The likely magnitude of this effect clearly points out the need for more detailed consideration of the energy and electricity consumed in the production of office and telecommunications equipment.

[149] To illustrate this point, say that production of a PC consumed 1,000kW-h in Y1997, at a production cost of $500, which translates into an energy-to-output ratio of 2 kW-h of electricity per $ of output. If in Y2000, the "energy efficiency" of production increased by 50% and the "economic efficiency" improved by 25%, the energy-to-output ratio would decrease to 667kW-h/$400 = 1.67kW-h/$. However, if the "energy efficiency" improves by 50% and the "economic efficiency" by 25%, the ratio grows to 800kW-h/$333 = 2.4kW-h/$. In either case, the Y2000 sales volume (in $) determines the *net* energy impact.

8.4 e-Commerce

E-Commerce, short for “electronic commerce,” denotes the myriad of ways in which the transmission of content via electrons can substitute for the exchange of physical goods. On-line shopping and banking, electronic music files and books, automated business-to-business (B2B) exchanges, auctions, and purchasing systems are all manifestations of e-Commerce. E-Commerce has long existed in certain forms (e.g., banking and stock trading), and its impact increased when the public began embracing the Internet on a larger scale in the mid-1990s. Telecommunications and computer networks, along with servers and data storage devices, form the backbone of e-Commerce and make it possible. Other devices, including computers and monitors and printers, enable people to directly interact and exchange information with other people and content on these networks.

The automation of business processes, particularly in the back office, offers the potential for greatly improved process efficiency and significant cost savings. For some, e-Commerce, the process of conducting business over the web, holds great promise to reduce national energy consumption in several ways. Upon further inspection, e-Commerce also has the potential to increase national energy consumption. In any case, the net impact of e-Commerce upon national energy consumption remains unclear and very resistant to quantification, as e-Commerce remains in a relatively nascent stage in the context of the entire U.S. economy. This section strives to explain in a qualitative sense how the e-Commerce enabled by office and telecommunications equipment may ultimately impact national energy consumption.

Romm et al. (1999), Cozzi (2000), and Matthews (2001) all discuss the potential impacts of e-Commerce and the Internet upon national energy consumption, primarily on a qualitative level but also with specific quantitative examples. However, we could not find any comprehensive effort to estimate or predict the qualitative impact of e-Commerce upon national energy consumption.

Table 8-4 summarizes several ways that e-commerce may impact national energy consumption.

Table 8-4: Potential Ways that e-Commerce May Impact National Energy Consumption

What e-Commerce Enables	*How it Could Decrease Energy Consumption*	*How it Could Increase Energy Consumption*
Improved Supply Chain Management	Less unwanted production; decreased inventories reduced warehouse floorspace	
On-Line Shopping (Personal)[150]	Fewer trips to stores; reduced retail space	Increased demand for goods without displacing retail floorspace; more "next day" express shipping
Electronic Transactions (Business-to-Business)	Reduction of errors (unwanted goods and inventory); eliminate most paper involved in transactions	Decreased cost of goods increases demand
Superior Communication between Distant Business Units, Companies	Decreased need for business travel	Improved communication enables and enhances personal relationships, increasing travel
Greater Telecommuting	Reduces personal travel to workplace; decrease in office space required	Additional errands run during the day; increased home energy consumption
Electronic Auctions of Goods and Services	Improved utilization of existing resources	Increased volume of transactions
e-Materialization	Substitutes electronic media for physical copy (e.g., .PDF for a book)	Greater overall demand for products, i.e., de-materialized *in addition* to material goods

In each of the general cases shown above, it is not completely clear if e-commerce reduces or increases national energy consumption. Looking solely at the direct impact of the measures seems to show that most measures reduce energy consumption. For example, in the back-office realm, Cisco (Economist, 2000d) switched from a conventional ordering system to an on-line system, reducing its order re-work rate from 25% to 2% and saving the company $500M. As a result, corporate productivity increased while energy intensity decreased. Matthews (2001) also notes the potential for IT equipment, often integrated with smart sensors, to achieve large national savings via improvement of device (an automobile) or system/process efficiency. For instance, a Miller brewery installed a computer-based factory monitoring system integrated with a plant-wide intranet. The system improved process monitoring, as well as aided production scheduling, resulting in a decrease in the level of waste bottles and cans from 5% to 0.1% of production (Ebusinessforum.com, 2001). On-line B2B exchanges, which match up sellers and

[150] The UCLA Center for Communication Policy (2000) report addresses several topics surrounding the Internet and society, including survey-based results of consumer perceptions and use of on-line shopping,

buyers in different industries, also promise to improve efficiency. For example, according to the Economist (1999), about one-half of all trucks on the road carry no goods and are simply traveling to their next destination. A transportation exchange enables shippers to bid for unfilled space in truck fleets, augmenting the trucking company's profits of the truck's capacity while also saving energy.

On the other hand, all economic decisions have ramifications that cascade well beyond the direct impact of their purchase, making consideration of the system impact over the entire economy very important. In energy terms, some "rebound" is inevitable and the magnitude of this "rebound" effect, i.e., how much of the direct energy savings are eliminated by other activities, is not well established for most examples discussed in Table 8-4. We now presents a few examples that illustrate possible energy savings arising from the applications of office and telecommunications equipment and how the "rebound" effect may compromise those gains in each case.

At first glance, on-line "virtual storefronts" (replacing brick and mortar establishments) can greatly decrease the amount of energy required to operate the business by substituting warehouses for retail space and increasing storage densities. A study cited by Romm et al. (1999) estimates that Amazon.com, by substituting low-energy warehouse floorspace for high-energy retail space and maintaining low inventories, consumes *16 times less* energy per dollar of sales than a conventional (retail-space) bookstore. However, on-line bookstores could force down the price of books, increasing the economy-wide demand for books as well as the national energy consumption to produce and transport books. Moreover, if on-line sales do not actually displace physical bookstores, the energy used to support the infrastructure of on-line booksellers would not replace but supplement the energy already consumed in the retail sector[151]. In sum, on-line sales have an unclear effect on national energy consumption.

Similarly, Matthews (2001) points out that net impact of telecommuting and telework (T&T) on national energy consumption remains ambiguous. Enabled by IT, T&T directly saves energy, both by reducing automobile mileage to and from work and also by displacing floor space, in this instance office space. To site one example, AT&T hopes to reduce office floorspace per employee by about 1/3rd in 2003 (relative to 1998; Romm et al., 1999) through vigorous promotion of telecommuting, which would lead to similar savings in office space energy consumption. In turn, reduced floorspace demand would decrease energy consumed in the construction sector, both directly (energy used to put up a building) and indirectly (energy consumed throughout the construction materials supply chains). As with on-line sales, the rebound effects bring the savings of T&T into question.

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[151] For example, shopping is not simply about the purchase; it is, for many, a pleasurable activity for which an on-line alternative cannot readily substitute. In addition, people harbor security concerns about using their personal information online which can impede the development of e-commerce (Economist (2000b).

People who elect T&T may choose to live further from the office, increasing automobile mileage in general and specifically on days the employee does go to the office. In addition, people working at home may take advantage of their freedom to run more errands, consuming additional energy in the process. Finally, the employee will consume additional energy in her home.

Overall, several international studies predicts T&T will produce a net decrease in energy consumption (Matthews, 2001), but the degree to which employees will adopt T&T is unclear. In some cases, T&T may be a favorable alternative for workers who spend much time out of the office (e.g., sales personnel). On the other hand, a workplace fills important social, collegial need for many people, and provides important informal communication opportunities for workers. Realizing significant energy savings from telecommuting – if they exist - would require a significant shift in personal behavior and would likely only occur gradually over more than a decade.

The transportation sector clearly illustrates the difficulty in projecting national energy savings from e-commerce. For example, at first glance, a person ordering three books online reduces the energy consumed to acquire the books because the shipment to the front door via ubiquitous U.S. Post Office shipping (or a private delivery company) supplants an automobile trip to a store. However, many goods are shipped via air freight, which consumes almost as much energy as an auto trip. Furthermore, even if they did by the books online, the family might make the same automobile trip to buy something else at the same location or make a different trip instead, in which case the online order would show a net negative impact upon energy consumption in the transportation sector. Indeed, Matthews et al. (2001) suggests that the net energy outcome is very sensitive to the input assumptions, particularly the distance of the family's automobile trip. Presumably, the quantity, size and weight of any other items during the trip also influences the balance, as combining purchases on an automobile trip should decrease the portion of mileage attributed to that item. In sum, on-line and traditional retailing appear to have similar *national* energy impacts.

Ultimately, cost savings, not the energy saved per se, drive companies to adopt e-Commerce strategies. The Economist (2000d) expects that the greatest savings will come from reduced procurement costs, citing a Goldman Sachs report that online purchasing could save firms somewhere between 2% and 40% per year. For this reason, Jupiter Research projects $2.2 trillion in B2B e-commerce by 2005[152] (see Enos, 2001). Only when businesses adopt e-Commerce on such a larger scale will the net and potential impact of office and computer equipment via e-Commerce upon national energy consumption become clearer.

[152] This estimate comes in much lower than earlier estimates, e.g., $6.3trillion in 2005 (Jupiter Research, 2000) and $4trillion by 2003 (Gartner Group, from Economist, 2000d).

8.5 Structural Changes in the Economy from the Growing Importance of the IT Sector

Office and telecommunications equipment can also alter energy consumption in the economy as a whole in at least two ways. First, rapid growth in the low energy intensity IT sector decreases the energy intensity of the entire economy by shifting a larger portion of the U.S. economic output to lower energy intensity activity. Laitner et al. (2000) report that the Information and Communication Technology Sectors were actually five times less energy intensive per dollar of economic activity[153] than the balance of the economy. Continued growth in this sector (to supply equipment and services) relative to the economy as a whole will reduces the linkage between electricity/energy consumption and GDP growth. They note that, over the 1990-1997 period, the ICT sector grew much faster than the U.S. economy as whole: 13.5%[154] in ICT versus 2.6% for the greater U.S economy. Similarly, Cozzi (2000) points out that the IT industries' share of total GDP grew from 6% in 1995 to about 8% in 1998 and that IT contributed more than one-third of real GDP growth over that period. Assuming the ICT growth trend does continue – the precipitous decline of ICT spending in Y2001 (Economist, 2001a) suggests strongly that it will not – it does not necessarily mean that the national energy consumption will decrease due to an increase in ICT activity. On the other hand, it does suggest that the national energy consumption *growth rate* would decrease.

Office and telecommunications equipment could also improve the productivity of the U.S. economy as a whole, which could reduce the amount of inputs required to generate goods and services (i.e., reduce the energy intensity of the U.S. economy).

From the mid-1970's until the mid-1990s, U.S. productivity grew very slowly in historical terms, in spite of widespread deployment of IT in businesses (see Figure 8-2). The apparently negligible impact of IT upon productivity became so well known that it gained a name: the productivity paradox. To quote Nobel Laureate economist Robert Solow from 1987, "You can see the computer age everywhere but in the productivity statistics" (Economist, 2000d). In a sense, this should not be surprising as prior revolutionary technologies, such as electricity, took long periods (decades) from their introduction to have a positive impact on economic productivity. It takes time to figure how best to leverage new technologies.

[153] Based upon an input-output model; Laitner (2001) indicates that this applies only to *direct* energy consumption, not the entire supply chain.

[154] Economist (2000d) cites a 24% annual growth for IT goods in the 1990s.

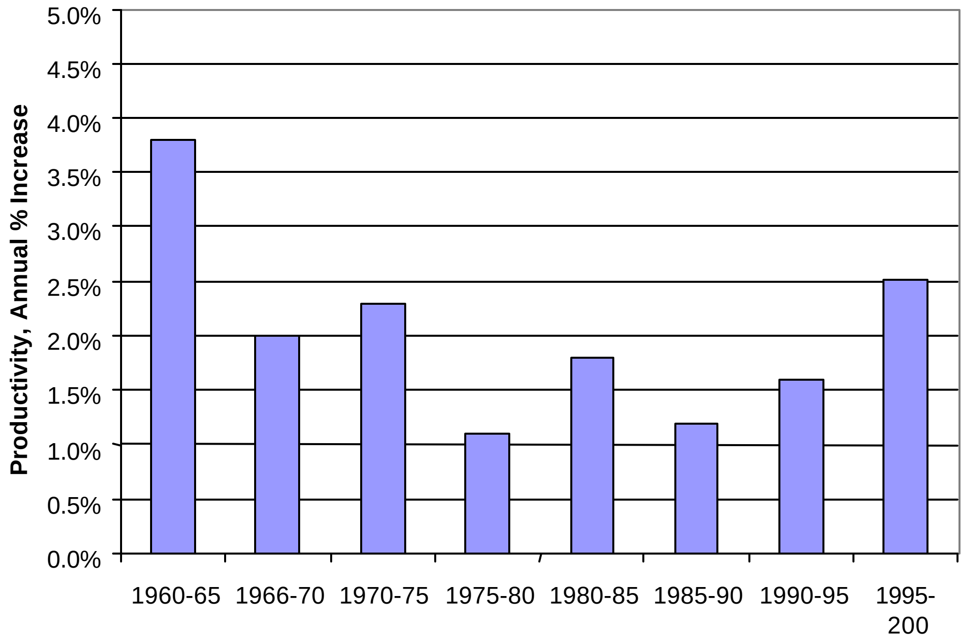

Figure 8-2: U.S. Productivity Growth Rates (Non-Farm Rates) (from Economist, 2001c)

As shown in Figure 8-2, U.S. productivity began increasing dramatically in the mid-1990s. The degree to which IT is responsible for the increase in productivity is unclear and subject to intense debate[155]. Many (e.g., Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000) attribute much of the up-tick to IT. Other economists, such as Robert Gordon at Northwestern University, argue that the productivity gains primarily reflect the economic cycle and that all productivity gains have occurred in manufacturing (i.e., outside of the environment receiving the most IT investment [Economist, 2000d]). Another camp asserts that IT primarily augments product and service quality, attributes that are difficult to quantify in terms of macroeconomic measures used to measure productivity, such as GDP (Economist, 2000d)[156].

Certainly, the link between energy consumption and GDP growth (i.e., energy intensity) has decreased in recent years.

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155 For more discussion of this topic, see, for example, Economist, 2000d.

156 A convincing case can be made that such effects have always been difficult to quantify and prior productivity data similarly failed to account fully for product and service quality enhancements.

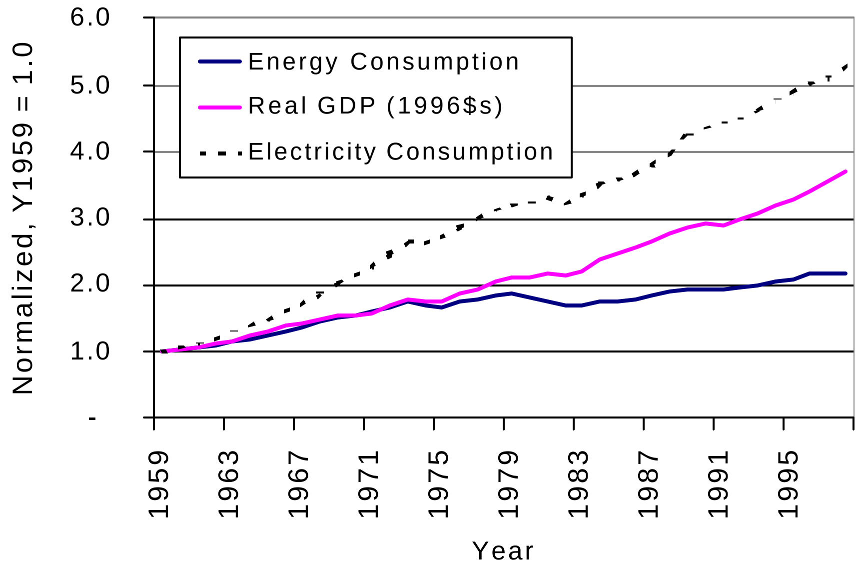

Figure 8-3: Annual U.S. Energy Consumption, Real GDP and Electricity Consumption, Normalized to Y1959

As shown in Figure 8-3 (based upon EIA [1999], U.S. Department of Commerce [1999], and EIA [2001c], respectively), economic growth and energy consumption moved in lock-step together until the oil crises of the 1970s. After about 1980, the link between real GDP growth and national energy consumption decreased, presumably due to higher energy prices. Romm et al. (1999) attribute the most recent decrease in energy intensity to the rise of the Internet:

> "While energy use will continue to rise throughout the next decade, the Internet economy appears to allow a certain amount of incremental growth that does not require as much energy and resource consumption as traditional economic growth. The impact of the Internet economy, coupled with other trends we have discussed … lead us to believe that from 1997 to 2007, the nation will experience annual declines in energy intensity (energy consumed per dollar of GDP) of more than 1.5%—and perhaps more than 2.0%."

As shown in Figure 8-4 (based upon EIA, 1999, and U.S. Department of Commerce, 1999), energy intensity did decrease at the highest rates seen since the time of high oil prices in the early 1980s.

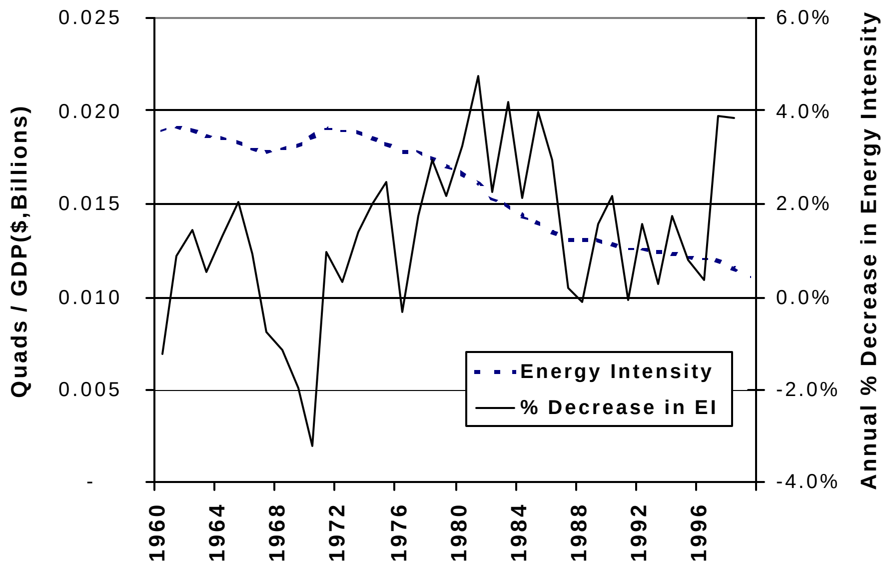

Figure 8-4: U.S. Energy Intensity and Energy Intensity Decrease, 1960 to 1998

That the decrease in energy intensity coincided with a period of historically low (in real terms) energy prices suggests that even if IT does not create a measurable increase in productivity, it still may decrease energy intensity.

However, because the higher rate of energy intensity decrease occurred only very recently, it appears premature to draw a solid conclusion from such a small data set. If IT-based innovations do accelerate the long-term decrease in energy intensity, the impact of office and telecommunications equipment on national energy consumption could be significantly larger than the ~1% of national energy consumed by those devices.

8.6 Paper Consumption

Several office equipment devices, namely printers, copiers, and facsimile machines, consume paper. Our AEC calculations take into account the energy consumed to print an image on the paper, but do not reflect the energy used to actually manufacture the paper. Nordman et al. (1998)[157] found that manufacturing a piece of paper from wood requires about 17W-h, one from recycled paper 12W-h. Put another way, making the paper consumes more than an order of magnitude more

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[157] See also: "Cutting Paper," at http://eetd.LBL.gov/Paper/ideas/html/index.htm .

energy than the ~1TW-h consumed to electrographically produce an image on the paper.

Consequently, the energy consumed to manufacture the paper consumed by copiers and printers in one year approaches ~20TW-h, which exceeds the total electrical energy consumed to operate all of the commercial copiers and printers during an entire year (see Table 8-5).

Table 8-5: Energy Consumed to Manufacture Paper, by Office Equipment Type

Machine Type	Paper Consumption, billions of sheets (from Table D-4)	Energy Consumption to Manufacture Paper Consumed, TW-h[158]
Laser Printer	608	9.1
Roll-Fed Laser Printers	492	7.5
Inkjet Printers	19	0.3
Copy Machines	154	2.3
TOTAL AEC, Paper Production, TW-h		19.2

Section D.2 of Appendix D offers more detail about the energy consumed to make the paper.

8.7 Disposal of Obsolete Devices

Many office equipment types have short lifetimes of four years or less, including PCs (three years) and CRT monitors (four Years). The National Safety Council (1999) projected that about 300 million PCs and CRT monitors will reach obsolescence over the Y2000-Y2003 period, driven by a projected decrease in PC lifetime to about two years and continued growth of the PC stock (see Table 8-6).

Table 8-6: Projections of Obsolete PCs and Monitors, by National Safety Council (1999)

Year	PCs millions	CRT Monitors, millions
2000	31.6	28.4
2001	41.9	27.6
2002	55.4	26.8
2003	63.3	26.1
TOTAL	192.2	108.9

[158] Assuming 15W-h per sheet of paper.

Together, a CRT monitor and computer can contain four pounds of lead, as well as mercury in backup batteries and cadmium in circuit boards (Consumer Reports, 1999), all toxic materials that can create groundwater problems if sent to landfills.

Recycling offers the potential to reduce the direct impact environmental of obsolete office and telecommunications equipment and some jurisdictions have been very aggressive in targeting this equipment for recycling. For example, the state of Massachusetts has made recycling (as of 1999) of monitors and TVs mandatory and allows curbside pick-up of these devices (Consumer Reports, 2000), as well as computers. Nonetheless, the U.S. as a whole currently recycles only about 10% of the PCs and monitors that reach obsolescence each year (see Figure 8-5). Recycling rates are projected to increase in the foreseeable future; still, several hundred million PCs and monitors will be discarded between Y2000 and Y2007.

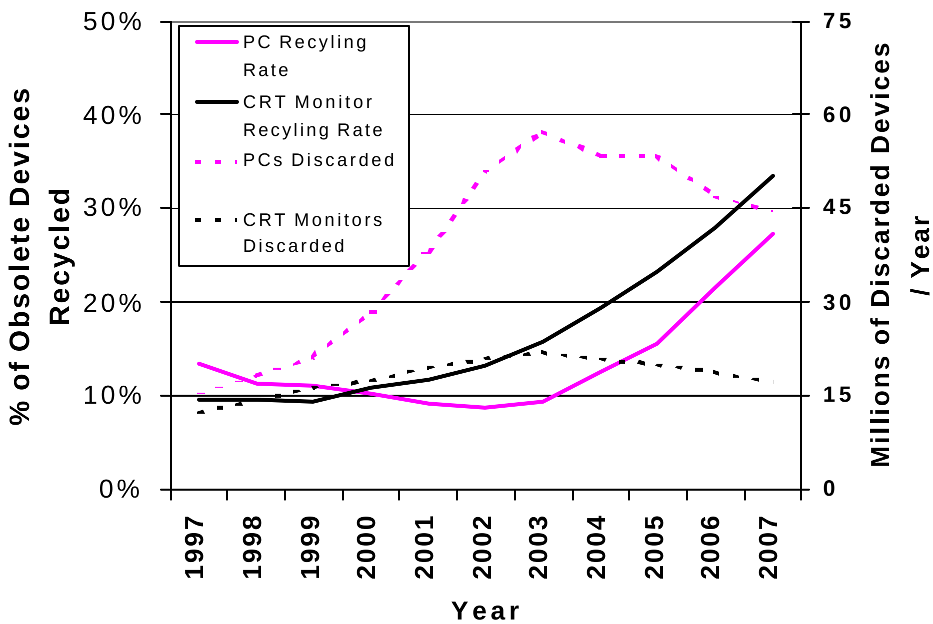

Figure 8-5: PC and CRT Monitor Recycling Rates (from National Safety Council, 1999)

Reuse can extend the lifetime of equipment by increasing the stock of equipment while reducing equipment disposal rates. Some organizations accept computer donations from businesses and government organizations, re-furbish the computers, and provide them to people unable to afford a computer. Computers for Students in the Northern Virginia strips down used computers, upgrades outdated components (adding a CD-ROM, modem, larger hard drive, often more RAM), and provides the computers to students in lower income families. On average, each computer costs ~$200-250 to reclaim. In addition, a small portion of obsolete equipment is exported outside of the U.S. (National Safety Council, 1999).

In light of the hazards posed by lead, Perry (2000) reports that Europe and Japan may move to greatly reduce or eliminate lead content in electronic devices. He notes that the European Community draft revisions in 1999 on directive "Waste from Electrical and Electronic Equipment" include take-back provisions that would make manufacturers of electronic goods take responsibility for entire product life cycle. Consumer electronics giant Sony planned to eliminate lead from all of their domestic (Japan) products in Y2000, and from all of their products in Y2001. The global nature of the IT market might leave U.S. manufacturers and the U.S. market little choice but to also manufacture similar products.

In spite of action outside of the U.S., office equipment re-use and exportation in the U.S. occurs on far too small a scale relative to expected device obsolescence rates. It appears very likely that hundreds of millions of pieces of office and telecommunications equipment will indeed enter U.S. landfills over the coming decade.

9 Summary Conclusions and Recommendations

9.1 Summary/Conclusions

The bottom-up analysis of the annual energy consumption (AEC) of non-residential office and telecommunications equipment revealed that the equipment consumed about 1.1 quad (primary energy) or 97-TW-h of electricity (site) in the year 2000. Placed in a larger context, the AEC of non-residential[159] office and telecommunications equipment represents about 3% of national electricity consumption and equals ~9% of all electricity consumed in commercial buildings. In primary energy terms, the non-residential office and telecommunications equipment sector accounts for just over 1% of national energy consumption.

The ten equipment types selected for further study consumed 88TW-h, almost 90% of sector electricity consumption (see Table 9-1).

Table 9-1: Office and Telecommunications Equipment Annual Electricity Consumption Summary

Device Type	AEC (TW-h)	% of AEC
Communications Networks	30.3	31%
Server Computers[1]	11.6	13%
Telephone Network Equipment[2]	6.6	7%
Computer Network Equipment[3]	6.4	7%
UPSs	5.8	6%
Monitors and Displays	22.2	23%
Monitors	18.8	19%
General Displays	3.4	4%
PCs[4]	19.6	20%
Imaging Devices	15.4	16%
Copiers	9.7	10%
Printers	5.7	6%
OTHER	9.7	10%
TOTAL	97	100%

[1] Includes Data Storage.
[2] Includes: Cell site equipment, transmission (fiber optic), public phone networks, PBXs, wireless phones.
[3] Includes: LAN switches, routers, hubs, WAN switches, Modem / RAS, CMTS.
[4] Includes: Desktop PCs, laptop PCs, workstations.

[159] Includes equipment in commercial and industrial buildings, as well as telecommunications equipment not in buildings (e.g., on pedestals, cell towers, etc.).

Communication network equipment accounts for over 30% of all office and telecommunications equipment AEC, or an average of 26W[160] for each of the approximately 133 million PCs (non-residential and residential PCs) in the U.S.

We developed three scenarios to serve as the basis for projections of future sector electricity consumption: "Ubiquitous Computing," "The PC Reigns," and "The Greening of IT". These scenarios yielded a wide range of potential future electricity consumption values, ranging from 83TW-h to 117TW-h in Y2005 and 67TW-h to 135TW-h in Y2010, compared to a 85TW-h Y2000 baseline for the equipment (includes *only* key equipment types; see Figure 9-1).

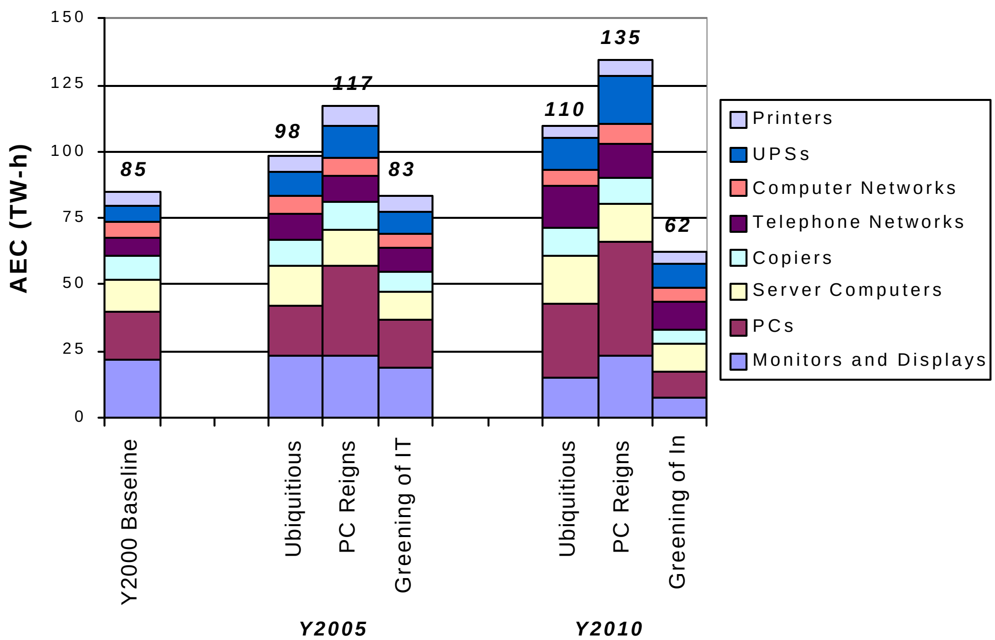

Figure 9-1: Key Equipment Type Projected Annual Energy Consumption, by Scenario

The Y2010 value projected for the "PC Reigns" scenario translates into a sector electricity consumption compound annual growth rate of 4.7%. In addition, the scenarios clarified key trends and technologies that will influence future energy consumption. Widespread replacement of desktop PCs and monitors with laptop computers would create the largest decrease in AEC, while increases in PC microprocessor power draw would lead to the greatest increase in AEC.

[160] Averaged over 8,760 hours per year.

Compared to other recent studies of commercial office and telecommunication equipment AEC, the ADL AEC estimate exceeded that of Kawamoto et al. (2001) by about 20% for equipment types considered by both studies[161] (see Figure 9-1). It is important to note that the current study considers a broader range of equipment than both recent studies, making the raw AEC sums shown in Figure 9-2 not directly comparable[162].

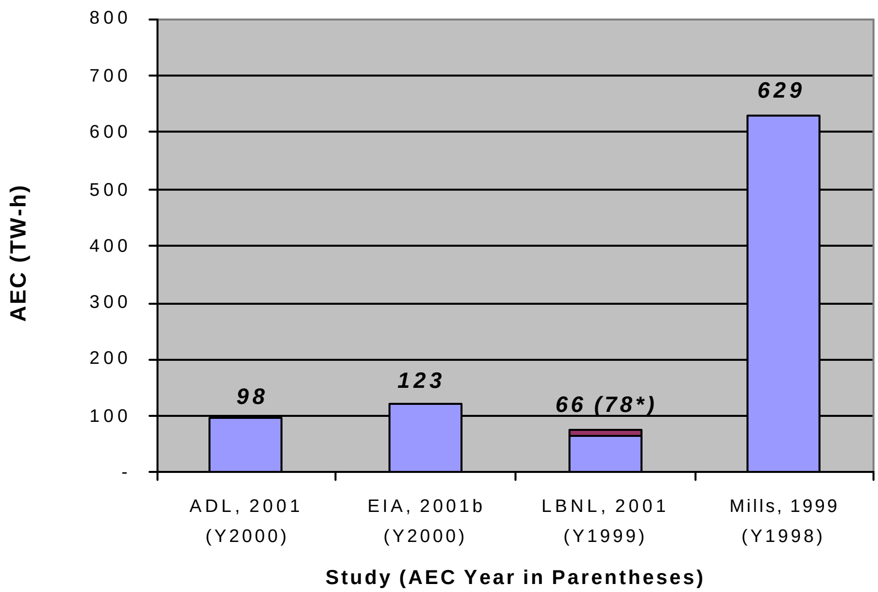

Figure 9-2: Comparison of Recent Office and Telecommunications AEC Studies[163]

More specifically, personal computer, monitor, and copier AEC estimates are substantially higher than those of Kawamoto et al., primarily because the current study incorporated more recent device night-status survey results that increased device usage, thereby increasing electricity consumption. On the other hand, lower

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[161] PCs (desktop and laptop, workstations), monitors, general displays, laser printers, inkjet/dot matrix printers, copy machines, server/mainframe/mini computers, data storage, facsimile machines, computer network equipment.

[162] The Mills (1999) data reflects a linear extrapolation of his values for internet-related equipment to his entire installed base of commercial equipment; see Section 6.3 for a more complete explanation and calculations.

[163] The 66 TW-h value reflects that shown in Kawamoto et al. (2001).

* The 78TW-h value shown for Kawamoto et al. (2001) equals the sum of the Kawamoto et al. (2001) value and the telephone central office (CO) AEC estimate of 12TW-h from Koomey et al. (1999).

stock estimates and power draw values, respectively, resulted in significantly lower AECs for laser printers and server computer. Overall, the current study takes into account a wider range of data sources, uses a more refined breakdown of several equipment types, and considers a broader range of equipment than Kawamoto et al. (2001), leading to a more accurate and comprehensive AEC estimate.

In contrast, it proved difficult to make a meaningful comparison between our study and Mills' (1999) Y1998 estimate, in part due to the different equipment categorization approaches used by the two studies. The best attempt at organizing the AEC values of Mills shows that Mills exceeded the current study AEC estimate by more than a factor of six. Mills consistently selected devices at the upper end of the power draw range and applied the power draw to the entire stock (e.g., using the power draw of a high-end supercomputer to represent the power draw of all "mainframe" computers).

Our study also discussed and qualitatively evaluated the indirect effects of office and telecommunications equipment upon national energy consumption and the environment.

- During the cooling season, the heat dissipated by office and telecommunications equipment increases air conditioning loads, while during the heating season it effectively replaces a portion of the heating load with electric resistance heating. On the balance, the very high density of office equipment in office buildings, buildings that tend to have greater cooling than heating loads, most likely results in a net increase in HVAC loads in the population of commercial buildings.

- Office and telecommunications equipment increases peak power demand in three ways: first, by direct equipment power draw during peak periods, augmented by the poor power factors of much office and telecommunications equipment; second, from increased air-conditioning loads generated by the equipment; and third, increased transmission and distribution losses caused by the poor power factors of much office and telecommunications equipment. Overall, commercial office and telecommunications equipment likely increases the peak power demand within a given geographical region by about 3 to 4%.

- An imbedded energy study reveals that the AEC to manufacture office and telecommunications equipment is of the same magnitude as the energy directly consumed during operation of the devices each year.

- Several researchers have posited national energy savings from accelerated growth of the ratio of energy consumption per $ of GDP (i.e., energy intensity) due to e-commerce. Although internet e-commerce can potentially improve economic efficiency in numerous ways, it is premature to state that recent increases in the rate of energy intensity decrease are permanent. In addition, e-commerce remains very young with minimal exploitation on the scale of the entire economy, suggesting that it will take some time before e-commerce could have a major impact on nation energy consumption. Ultimately, over a period of many years, the internet and e-commerce will likely have the most dramatic impact upon national energy consumption of any indirect impacts of office and telecommunications equipment. Similarly, structural changes in the economy from the growing importance of the less-energy intensive IT sector during the 1990s could play a future role in abating national energy intensity in the future. However, the dramatic downturn in 2001 suffered by IT brings into question the strength and duration of this trend.

- The paper consumed by office equipment in one year requires more energy to manufacture than all of the copiers and printers consume directly in that same year.

- Literally hundreds of millions of obsolete office and telecommunications devices will go into landfills over the next decade, in spite of moderate increases in office and telecommunications equipment recycling rates.

9.2 Recommendations for Further Study

The opportunity to investigate the energy consumed by non-residential office and telecommunications equipment has provided much insight into several areas that would benefit from further study.

Energy Savings Opportunities: The current study identified the office and telecommunications equipment devices that consume the most electricity, as well as the technologies employed and under development within the key equipment types. Several examples of energy savings opportunities include:

- Increasing ENERGY STAR® enabled rates
- Increasing "night-off" rates
- Liquid crystal and organic light-emitting diode displays
- Low-power and flexible architecture microprocessors
- Lower-temperature fuser rolls for copiers and laser printers.

A thorough study of energy savings opportunities to clarify the magnitude and economics of promising energy-efficiency opportunities is in progress for DOE, as a second volume to this study.

Equipment Usage Surveys: A dominant portion of the difference between the monitor, PC, and copier AECs in this study and Kawamoto et al. (2001) arose because the current study used incrementally more recent equipment night-status data. These data increased the unit energy consumption estimate of some devices by up to 50%, demonstrating a very high sensitivity of office and telecommunications equipment AEC to usage times and survey data. While, survey data are expensive to acquire, but continuing to record them is crucial to accurately quantifying office and telecommunications equipment AEC, as well as the actual success of the ENERGY STAR® program for office equipment. We advocate performing larger-scale equipment usage surveys to reduce uncertainties in usage data, and carrying out surveys over a broader geographic range to reduce possible geographic biases in the data sets.

Uninterruptable Power Supplies: This report offers the first estimate of the energy consumed by UPSs. We recommend carrying out an in-depth study of UPSs would further refine these estimates by clarifying the range of UPSs specifically used for office and telecommunications equipment devices by power class and technology, as well as measuring actual UPS loads and efficiencies relative to UPS rated power.

Public Telephone Network: The literature review for this project did not find any studies analyzing the AEC of telephone networks. Thus, to our knowledge, our study also presents the first estimate of the energy consumed by telephone network equipment in the U.S. We believe that the public telephone network AEC requires further study to reconcile the difference between our estimate 1TW-h analog public phone line AEC and the telephone central office (CO) AEC estimates of 12TW-h (Koomey et al., 1999) and 22TW-h (Allenby, 1999). Undoubtedly, fiber optic terminals account for a portion of the difference, as do the relatively small quantity of internet access devices potentially housed at COs, but they cannot account for most of the difference.

Indirect Impacts of office and telecommunications equipment: Our report has touched on several of the main indirect impact of office and telecommunications equipment, all of which warrant further, more detailed study. As noted in the preceding section, productivity enhancements enabled by IT ultimately have the potential to exceed the impact of direct energy consumption by office and telecommunications equipment upon national energy consumption. We feel that developing a more complete understanding of this effect and its magnitude is crucial to developing more accurate projections of future national electricity demand and consumption. In addition, we believe that studying the impact that office and telecommunications equipment has upon peak electricity demand warrants study, given the constraints of the national electricity grid. This investigation would focus not only on the device power draw, but also increases in air-conditioning loads, increased transmission and distribution losses, and higher power plant demand required to satisfy the reactive load imposed by the low power factors of much office and telecommunications equipment. Finally, the energy embodied in the equipment produced in a single year appears to equal a significant fraction of the energy directly consumed by the total equipment installed base in one year. Some of the data used to calculate this estimate may be dated, but the apparent magnitude points out the need for a more thorough study of the energy embodied in office and telecommunications equipment.

References

ADL, 1993, “Characterization of Commercial Building Appliances”, Final Report prepared for U.S. Department of Energy, Office of Building Technologies, August.

ADL, 1999, “Energy Consumption Characteristics of Commercial Building HVAC Systems Volume 2: Thermal Distribution, Auxiliary Equipment, and Ventilation”, Final Report by Arthur D. Little, Inc., to the U.S. Department of Energy, Office of Building Technology, State and Community Programs, October.

ADL, 2000, “Preliminary Assessment of Battery Energy Storage and Fuel Cell Systems in Building Applications”, Final Report to National Energy Technology Laboratory, U.S. Department of Energy, 2 August.

ADL, 2001, “Energy Consumption Characteristics of Commercial Building HVAC Systems Volume 1: Chillers, Refrigerant Compressors, and Heating Systems”, Final Report by Arthur D. Little, Inc., to the U.S. Department of Energy, Office of Building Technology, State and Community Programs, April.

Agarwal, A., 1999, “Raw Computation”, *Scientific American*, August.

Akatsu, M., Anderson, D., Brown, J., Bui, A., Bulat, G., Ernst-Jones, T., Griffith, G., Olhava, S., Paoli, K., and Stephen, B., 1999, “Worldwide PC Forecast Update, 1999-2003”, IDC Report #20599.

All, A., 2001, Personal Communication, Response to post on ATMMarketplace.com in April.

Allenby, B., 1999, “Telework – The AT&T Experience”, Testimony Before the U.S House of Representatives Committee on Education and the Workforce, on 28 October. Available at: http://www.davidbonior.house.gov/ed_workforce/hearings/106th/oi/telework102899/allenby.htm .

Amatruda, R. and Brown, P., 2000, “Worldwide Tape Drive Forecast and Analysis, 2000-2004”, IDC Report #23080.

APC, 2001, “The Different Types of UPS Systems”, Technical Note #T1, American Power Conversion Corporation. Available at: http://159.215.19.5/kbasewb2.nsf/For+External/6681E24551A75E388525672300568CB2?OpenDocument .

Appliance Magazine, 2000, “23rd Annual Portrait of the U.S. Appliance Industry”, *Appliance Magazine*, September, pp. 87-89.

Azar, K., 2000, “The History of Power Dissipation”, *Electronics Cooling Magazine*, Vol.6, No.1.

Bank Network News, 2000, “VeriFone Loses Ground But Promises 2000 Gains”, *Bank Network News*, Vol. 18, No. 19, p. 1.

Barthel, C., Lechtenbohmer, G.S. and Thomas, S., 2000, “GHG Emission Trends of the Internet in Germany”, Discssion Paper for the Japanese-German Workshop “International Climate Policy and the IT Sector,” November.

Basel, W., 2001, “Pillars Supporting Tech Have Toppled”, The Dismal Scientist, 15 March, 2001, posted at: http://www.dismal.com/todays_econ/te_031501_2.asp .

Blazek, M., 2001, Personal Communications, AT&T.

Blazewicz, S., 2001, Personal Communication, Arthur D. Little, Inc.

Boedecker, E., 2001, Personal Communication, Energy Information Administration / U.S. Department of Energy.

Boyes, D., 2001, Personal Communication, Sine Nomine.

BTS, 2001, “2001 BTS Core Data Book”, U.S. Department of Energy, Office of Building Technology State and Community Programs, Dated 13 July. Available at: http://btscoredatabook.eren.doe.gov/.

Business Communications Company, Inc..1998, “*Uninterruptible Power Supply Systems: Continuous Data and Network Systems - Market Overview, Power Environment, UPS Technology, Components, Industry Competitiveness and UPS Markets*”, from Business Communications Company, Inc., March.

Carnegie Mellon University Green Design Initiative, 2001, Economic Input-Output Life Cycle Assessment (EIO-LCA) model [Internet]. Available at: http://www.eiolca.net/ , accessed 11 June.

CEA, 2001, “U.S. Household Penetration of Consumer Electronics Products”, Consumer Electronics Association, Market Research, January.

Cellular Telephony Industry Association (CTIA), 2000, “CTIA’s Semi-Annual Wireless Industry Survey”, Issued 31 December, 2000. Available at: www.ctia.org.

COMSYS, 2001, “VSAT Markets 2000: Report to Clients, v1.5”, Communication Systems Limited.

Consumer Reports, 1999, “Recycling Old Hardware”, *Consumer Reports*, September, p. 32.

Copeland, T.G., Ph.D. and Yokley, K.M., 2000, “Worldwide Workstation Census: Forecast and Analysis, 1999-2004”, IDC Report #22183.

Cozzi, L., 2000, “Information Technology-Internet and Energy Use: An Overview”, Internal Paper, International Energy Agency.

Dahlquist, K. and Borovick, L., 2000, “Worldwide LAN Switch Market Forecast and Analysis, 2000-2004”, IDC Report #22925.

Dahlquist, K., Hwang, D., Giusto, R., Akatsu, M., Brown, A., Martinez, A., Paoli, K., Yeo, D., Bulat, G., 2000, “IDC's Portable PC Five Year Forecast Update, 2000-2004”, IDC Report #22304.

Davidson, P., 2000, “U.S. Facsimile Machine and Fax MFP Market Forecast and Analysis, 1999-2003”, International Data Corporation (IDC), Table 16.

Davis, A., 2001, Personal Communication, Silicon Graphics, Inc, February.

Dell, 2001, Personal Communication, Dell Technical Assistance, Dell Computer Company, February.

Dower, J., 2001, Personal Communication, Boston ECR.

ebusinessforum.com, 2001, “Miller Brewing: Cutting Waste in the Production Line”, 7 May, reprinted by ebusinessforum.com with permission of *Net Profit*.

Economist, 1997, **Pocket World in Figures: 1997 Edition**, The Economist Books Ltd.: London, UK.

Economist, 1999, “Survey: Business and the Internet”, *The Economist*, 26 June.

Economist, 2000a, “Cause for conCERN?”, *The Economist*, 28 October, pp. 75-76.

Economist, 2000b, “Paying Online: Feeling Insecure”, *The Economist*, 28 October, p. 73.

Economist, 2000c, “The PC is Dead – Long Live the PC”, *The Economist*, 16 December, pp. 73-74.

Economist, 2000d, “A Survey of the New Economy: Untangling e-Conomics”, *The Economist*, 23 September.

Economist, 2001a, “From Investment Boom to Bust”, *The Economist*, 3 March, p. 72.

Economist, 2001b, “Computer Displays: Lightening Up”, *The Economist*, 2 June, pp. 82-83.

Economist, 2001c, “American Productivity: A Spanner in the Productivity Miracle”, *The Economist*, 11 August, pp. 55-56.

Economist Technology Quarterly, 2000A, “Digital Ink Meets Electronic Paper”, *The Economist,* 9 December, pp. 19-22.

Economist Technology Quarterly, 2000B, “Is Bluetooth Worth the Wait?”, *The Economist,* 9 December, pp. 12-14.

Economist Technology Quarterly, 2001, “Computing Power on Tap”, *The Economist*, 23 June, 2001, pp. 16-20.

EIA, 1997, "A Look at Residential Energy Consumption in 1997", Residential Energy Consumption Survey (RECS), U.S. Department of Energy, Energy Information Agency.

EIA, 1998, “Personal Computers and Computer Terminals in Commercial Buildings” from 1995 Commercial Buildings Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration, October 1998, DOE/EIA-0625 (95). Available at: http://www.eia.doe.gov/emeu/consumption/consumption briefs/pcsterminals.html .

EIA, 1999, “Energy Information Administration's 1999 Annual Energy Outlook”, Table “Energy Overview, 1949-1999”. Available at: http://www.eia.doe.gov/emeu/aer/overview.html .

EIA, 2000, “Country Analysis Briefs: United States of America.” Available at: http://www.eia.doe.gov/emeu/cabs/usa.html .

EIA, 2001a, “1999 COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY: REVISED AND NEW PRELIMINARY ESTIMATES”, Available at: http://www.eia.doe.gov/emeu/cbecs/char99/prelim1.htm#Table 7 .

EIA, 2001b, “Energy Information Administration's 2001 Annual Energy Outlook”, Table A5, "Commercial Sector Key Indicators and Consumption”. Available at: http://www.eia.doe.gov/oiaf/aeo/aeotab_5.htm .

EIA, 2001c, “Energy Information Administration’s 2001 Annual Energy Outlook”, Table 8.1, “Electricity Overview, 1949-2000”. Available at: http://www.eia.doe.gov/emeu/aer/elect.html .

Enos, L., 2001, “Study: B2B To Reach $137B by 2005”, *E-Commerce Times*, dated 8 January. Available at: http://www.ecommercetimes.com/perl/story/6515.html .

EPA, 1999, “Copier Memorandum of Understanding, Version 2.0”, dated November, 1999; Available at: http://estar.icfconsulting.com/epa/estar/partners/espartnerlogos.nsf/pdf/files/$file/copier.mou.v2.0.pdf .

Federal Communications Commission (FCC), 1998, “Fiber Deployment Update – End of Year 1998”, Report by The Industry Analysis Division, Common Carrier Bureau, September.

Federal Communications Commission (FCC), 2000a, “Trends in Telephone Service”, Report by The Industry Analysis Division, Common Carrier Bureau, March.

Federal Communications Commission (FCC), 2000b, “Infrastructure of the Local Operating Companies”, Report by The Industry Analysis Division, Common Carrier Bureau, October.

Floyd, D.B. and Parker, D.S, 1996, "Measured Performance of Energy-Efficient Computer Systems", Document: FSEC-PF-303, also presented at the Tenth Symposium on Improving Building Systems in Hot and Humid Climates, Fort Worth, Texas, May 13-14.

Forrester, 1999, “A New Server Landscape”, Forrester Research, Inc.

Frasco, A., 1999, “1999 U.S. Printer Market Review and Forecast, 1995-2003”, IDC Report #20331.

Freedonia Group, 2000, “Office Papers to 2003”, Report by The Freedonia Group.

Goldsmith, M. and Blazewicz, S., 2000, “An Electrical Systems Integration Perspective on Powering Internet Service Exchanges (ISXs)”, Report to the Electric Power Research Institute (EPRI).

Gubler, M., and Peters, M., 2000, “Use of Servers in Small and Medium-Sized Companies”, Abstract of Report, September, Swiss Federal Office of Energy: Research Programme “Electricity.”

Haas, L., 1998, “POS Paths Converge on Service”, *Computer Reseller News*, 28 September, p. 165.

Hipp, C., 2001, “Less is More”, Presented by Chris Hipp, RLX Technologies, at the E-Source HiDEL Summit, 1 May, Broomfield, CO.

Hosni, M.H., Jones, B.W., and Xu, H., 1999, “Measurement of Heat Gain and Radiant/Convective Split from Equipment in Buildings”, Final Report, ASHRAE Research Project 1055-RP, March.

House, J. and Hwang, D., 1999, “Size Matters: The Worldwide Smart Handheld Devices Market Review and Forecast, 1999-2003”, International Data Corporation (IDC), Report #W19319, July.

Huber, P.W. and Mills, M.P., 1999, “Dig More Coal – The PCs are Coming”, *Forbes*, 31 May, pp. 70-72.

IDC, 1999, “World Wide PC Forecasts Update”, International Data Corporation Report.

IDC, 2000, “U.S. PC Monitor Shipments, Average System Prices, and Revenues by Type and Size, 1999-2004”, International Data Corporation Publication.

Ishihara, T., Hayashi, K., Ito, K., and Hasegawa, J., 1998, “Encapsulated Toner Fixed by Low Temperature”, *Oki Technical Review*, no. 161, vol. 64.

ITIC, 2000, **Information Technology Industry Data Book, 1960-2010**, Information Technology Industry Council Publication.

Jackson, B., 2000, Personal Communication, Triton Systems.

Johansson, A., 1993, “Are Telephone Exchanges Energy Efficient?”, *Proceedings of Intelec 93: 15th International Telecommunications Energy Conference,* Paris, France, September; published by IEEE: New York, New York.

Johnstone, B., 2001, “A Bright Future for Displays”, *Technology Review*, April, 2001, p. 81-85.

Jorgenson, D.W. and Stiroh, K.J., 2000, “Raising the Speed Limit: U.S. Economic Growth in the Information Age”, *Brookings Papers on Economic Activity,* Vol. 2, pp. 125-212.

Josselyn, S., Hingley, M., Bozman, J., Cohen,L., 2000, “Server Market Forecast and Analysis, 1996-2004”, IDC Report #22538.

Jupiter Research, 2000, "Jupiter: B-To-B Online Trade Will Rise to $6.3 Trillion by 2005", 2 October. Available at: http://jup.com/company/pressrelease.jsp?doc=pr001002 .

Kawamoto, K., Koomey, J., Nordman, B., Brown, R., Piette, M.A., Ting, M.., and Meier, A., 2001, “Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices”, LBNL-45917. February.

Kendall, M., 2001, Personal Communication, Arthur D. Little, Inc.

Kmetz, K., 2000, "U.S. Analog and Digital Copier Market Forecast and Analysis, 1999-2004", IDC Report # 22807.

Komor, P., 1997, "Space Cooling Demands From Office Plug Loads", *ASHRAE Journal*, December, pp. 41-44.

Koomey, J.G., 2001, Personal Communication, Lawrence Berkeley National Laboratory.

Koomey, J.G., Kawamoto, K., Nordman, B., Piette, M.A., and Brown, R.E., 1999, "Initial Comments on 'The Internet Begins with Coal", Memorandum, LBNL-44698, 9 December. Available at: http://enduse.lbl.gov/SharedData/IT/Forbescritique991209.pdf .

Koomey, J.G., Cramer, M., Piette, M.A., and Eto, J.H., 1995, "Efficiency Improvements in U.S. Office Equipment: Expected Policy Impacts and Uncertainties", LBL Report: LBL-37383, December.

Kuhbach, P.D. and Planting, M.A., 2001, "Annual Input-Output Accounts of the U.S. Economy, 1997", *Survey of Current Business*, January, pp. 9-43. Available at: http://www.bea.doc.gov/bea/articles/national/inputout/2001/0101aio.pdf .

Kunz, M., 1997, "Energy Consumption of Electronic Network Components", Report of the "Electricity" Research Programme, Swiss Federal Office of Energy, Berne, Switzerland. Available at: http://www.electricity-research.ch/e.htm .

Laitner, 2001, Personal Communication, U.S. Environmental Protection Agency.

Laitner, J.A., Koomey, J.G., Worrell, E., and Gumerman, E., 2000, "Re-Estimating the Annual Energy Outlook 2000 Forecast Using Updated Assumptions about the Internet Economy", Paper Presented at the Eastern Economics Association Conference, Crystal City, VA, 24 March; also published as LBNL Report LBNL-46418.

Lanier, J., 2001, "Virtually There: Three-Dimensional Tele-Immersion May Eventually Bring the World to Your Desk", *Scientific American*, April. Available at: http://www.sciam.com/2001/0401issue/0401lanier.html .

LBNL, 2000, "Estimating Program Impacts of ENERGY STAR® Voluntary Labeling Programs," Spreadsheet ccap-l56.xls, last modified June 19. Available at: http://enduse.lbl.gov/Projects/ESImpacts.html on 26 March, 2001.

Loutfy, R., 2001, Personal Communication, Xerox Corporation.

Lovins, A.B., 1998, "Negawatts for Fabs: Advanced Energy Productivity for Fun and Profit", Presented to the NSF/SRC Environmentally Benign Semiconductor Manufacturing Engineering Research Center, August.

Ma, B., Burden, K., Scafidi, M.J., Olhawa, S., and O'Donnell, B., 2001, "Forecast and Analysis of the Worldwide Information Appliance Market, 2000-2005", IDC Report #24777.

MACEBUR, 1998, "Energy Efficient Office Technologies: the 1 Watt / 1 Volt-Ampere Challenge", Final Report of the MACEBUR Work Group, April.

Madsen, J.P., 2000, "Continuous UPS Availability: How Important is it to Your Company?", *Energy User News*, November, pp. 22-26. Available at: http://www.energyusernews.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2584,14489,00.html .

Maisy, 1998, "Large Commercial Customers: New Competitive Battleground", *Maisy Market Insights*, Jerry Jackson Associates, Ltd. Available at: http://www.maisy.com/isight1.htm .

Mam, J., 2001, Personal Communication, Tally Printer Corporation, Applications Division, March.

Mann, C.C., 2000, "The End of Moore's Law?", *Technology Review*, May-June, pp. 42-48.

Matthews, H.S., 2001, "The Environmental Implications of the Growth of the Information and Communications Technology Sector", Organisation for Economic Co-operation and Development (OECD) Report, Environment Directorate/Environment Policy Committee.

Matthews, H.S., Hendrickson, C.T., and Soh, D., 2001, "Environmental and Economic Effects of E-Commerce: A Case Study of Book Publishing and Retail Logistics," *Transportation Research Record*, in press.

Maul, J., 2001, Personal Communication, Arthur D. Little, Inc.

Mears, J. and Pappalardo, D., 2001, "Hosting Glut Should Mean Bargains for Companies", *Network World Fusion News*, dated 9 July. Available at: http://www.nwfusion.com/news/2001/0709glut.html .

Meier, A., 2001, Personal Communication, Lawrence Berkeley National Laboratory.

Meyer and Schaltegger, 1999, "Bestimmung des Energieverbrauchs von Unterhaltungselektronikgeraeten, Buerogeraeten und Automaten in der Schweitz", Report from Research Programme, Communication and Information Systems, Swiss Federal Office of Energy, Berne, Switzerland. Available at: http://www.electricity-research.ch/e.htm .

Miller Freeman, 1999, **Pulp and Paper North American Factbook 1999-2000**, (Miller Freeman, Inc.).

Mills, M.P., 1999, "The Internet Begins with Coal: A Preliminary Exploration of the Impact of the Internet on Electricity Consumption", A Green Policy Paper for the Greening Earth Sociey, May.

Mitchell-Jackson, J.D., 2001, "Energy Needs in an Internet Economy: A Closer Look at Data Centers", S.M. Thesis, Energy and Resources Group, University of California, Berkeley. Available at: http://enduse.lbl.gov/Info/datacenterreport.pdf .

MMTA, 2000, **2000 MultiMedia Telecommunications Association Market Book**, MultiMedia Telecommunications Association.

Moore, F., "Storage Infusion", A paper by F. Moore, President, Horison Information Strategies, for StorageTek Corp.

Nadel, S., Gordon, F., Neme, C., 2000, "Using Targeted Energy Efficiency Programs to Reduce Peak Electrical Demand and Address Electric System Reliability Problems", American Council for an Energy-Efficient Economy Report No. U008, November.

National Academy of Engineering, 1999, **Industrial Environmental Performance Metrics: Challenges and Opportunities**, (National Academy Press: Washington, D.C.).

National Safety Council, 1999, "Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States", Prepared by Stanford Resources, Inc., May.

Nemens, B., 2000, Personal Communication, Diebold, Inc.

NERC, 2001, "2001 Summer Assessment: Reliability of the Bulk Electricity Supply in North America", North American Electric Reliability Council, May. Available at: ftp://www.nerc.com/pub/sys/all_updl/docs/pubs/summer2001.pdf .

Nordman, B., 1998, "IEA-DSM Copier – Copier of the Future – Energy Estimates", LBNL Document, September.

Nordman, B., 2001, Personal Communication, Lawrence Berkeley National Laboratory.

Nordman, B., Piette, M.A., Pon, B., Kinney, K., 1998, “It’s Midnight…Is Your Copier On?: Energy Star Copier Performance”, LBNL, Environmental Technologies Division. LBNL Report LBNL-41332, February.

Nordman, B., Meier, A., Piette, M.A., 2000, “PC and Monitor Night Status: Power Management Enabling and Manual Turn-Off”, LBNL-46099.

Norford, L.K., Rabl, R., Harris, J., and Roturier, J., 1989, "Electronic OfficeEquipment: The Impact of Market Trends and Technology on End-Use Demand for Electricity," in **Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications**. (Lund University Press, 1989).

Norr, H., 2000, “Computers Contribute to Energy Crisis”, *San Francisco Chronicle*, 7 August.

NTIA, 2000, “Falling Through the Net, Toward Digital Inclusion: A Report on Americans' Access to Technology Tools”, National Telecommunications and Information Administration, Department of Commerce, October.

Oliner, S. and Sichel, D.E, 2000, “The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?”, *Proceedings from Federal Reserve Bank of San Francisco*.

PC Connection, 2001, Price for NEC 1700M LCD Monitor, *PC Connection* Catalog Received July.

Perry, T.S., 2000, “Technology 2000: The Environment”, *IEEE Spectrum*, January, pp. 81-85.

PG&E, 1999, “1999 Commercial Building Survey Report”, Pacific Gas and Electric Company. Available at: http://www.pge.com/003_save_energy/003b_bus/pdf/CEUS_1999.pdf.

Piette, M.A., Cramer, M., Eto, J., and Koomey, J., 1995, “Office Technology Energy Use and Savings Potential in New York”, LBL Report, LBL-36752.

Plante, J., 2000, “Uninterruptible Power Supplies: Parts1, 2, and 3”, *Electronic Buyers News* Power Supplement, September.

Plateberg, J., 2001, Personal Communication, Lucent Technologies.

Pottorf, C. and Vyas, C., 2000, “U.S. Wireless Services and Device Market Assessment, 1999-2004”, International Data Corporation.

Romm, J., Rosenfeld, A., Herrmann, S., 1999, “The Internet Economy and Global Warming: A Scenario of the Impact of E-commerce on Energy and the Environment”, VERSION 1.0, dated DECEMBER 1999, Published by the Center for Energy and Climate Solutions (CECS), a division of the Global Environment & Technology Foundation (GETF). Available at: http://www.cool-companies.org.

Rosen, K. and Meier, A., 2000, "Energy Use of U.S. Consumer Electronics at the End of the 20th Century", Proceedings of the 2nd International Conference on Energy Efficiency in Household Appliances and Lighting. 27-29 September 2000, Naples, Italy: Association of Italian Energy Economics (Rome). Available at: http://eetd.lbl.gov/EA/Reports/46212/ .

Rosen, K.B., Meier, A.K., and Zandelin, S., 2001, "Energy Use of Set-top Boxes and Telephony Products in the U.S.", LBNL Report LBNL-45305, June. Available at: http://eetd.lbl.gov/EA/Reports/45305/45305.pdf.

Roturier, J. and Harris, J.P., 1994, "New Loads in Office Buildings: Opportunities for Improving Efficiency of Office Equipment", Appearing in **Integrated Electricity Resource Planning**, A.T. de Almeida et al. Editors. (Kluwer Academic Publishers: The Netherlands), pp. 229-244.

Semenza, P., 2001a, Stanford Resources-iSuppli1996-2000 Monitor Shipment Data (communicated via e-mail), Stanford Resources-iSuppli.

Semenza, P., 2001b, Personal Communications, Stanford Resources-iSuppli.

Sezgen, O. and Koomey, J.G., 1998, "Interactions Between Lighting and Space Conditioning Energy Use in U.S. Commercial Buildings," LBNL Report LBNL-39795, April. Available at: http://enduse.lbl.gov/info/LBNL-39795.pdf .

Sheppard, E. and Gray, R., 2000, "1999 U.S. Disk Storage Systems Market Forecast and Analysis", IDC Report #21643.

Silva, E., 1998, "1998 LAN Hub Forecast, 1997-2002: The Switch Migration", IDC Report #17673.

Soares, J., 2001, "Electronic Paper Turns the Page", *Technology Review*, March, pp. 43-48.

Stein, J., 2001, "Welcome to the Wonderful World of HiDELs", Presented at the E-Source HiDEL Summit, 1 May, Broomfield, CO.

Stowe, T., 2000, Personal Communication.

Sturcke, S., 2001, Personal Communication, Seiko Epson Corporation.

Su, W., 1999, "U.S. Inkjet and Laser Printer Installed Base and Supplies Forecast, 1995-2003", IDC Report #21262.

Su, W., 2001, Personal Communication, International Data Corporation.

Taylor, J. and Hutchinson, J., 1999, “Uninterruptible Power Supplies, Parts 1, 2, and 3”, *Electronic Buyers News Powering the Next Millennium Supplement*, 18 October.

Technology Review, 2000, “Power Miser Chips”, November/December, p. 24.

Tennessen, J., 2001, Personal Communication, Cray, Inc.

U.S. Department of Commerce, 1999, “U.S. GROSS DOMESTIC PRODUCT: THIRD QUARTER 1999 (ADVANCE) REVISED ESTIMATES, 1959–99”, SURVEY OF CURRENT BUSINESS, November 1999. Available at: http://www.bea.doc.gov/bea/an/1199gdp/table6b.htm.

UCLA Center for Communication Policy, 2000, “The UCLA Internet Report: Surveying the Digital Future”, October. Available at: http://ccp.ucla.edu/pages/internet-report.asp .

Webber, C.A., Roberson, J.A.., Brown, R.E., Payne, C.T., Nordman, B., and Koomey, J.G., 2001, “Field Surveys of Office Equipment Operating Patterns”, Draft Report, LBNL-46930.

Wilkins, C.K. and McGaffin, N., 1994, “Measuring Computer Equipment Loads in Office Buildings”, *ASHRAE Journal*, August, pp. 21-24.

Wilkins, C.K. and Hosni, M.H., 2000, “Heat Gain From Office Equipment”, *ASHRAE Journal*, June, pp. 33-43.

Willard, C., Joseph, E., Goldfarb, D., and Kaufmann, N.J., 2000, “Worldwide High-Performance Technical Computer Census,1999”, IDC Report #22504, June.

Xenergy, 1999, “New Jersey Statewide Market Assessment”, Prepared for the New Jersey Utilities Working Group.

Yeager, K. and Stahlkoph, K., 2000, “Power for a Digital Society”, Paper presented at E-Vision 2000, Washington, D.C., 11-13 October.

Appendix A: AEC Calculations for Equipment Not Selected for Refined Study

A.1 Dictation Equipment

Our study considered three types of dictation equipment: portable, desktop, and dictation systems. Appliance Magazine (2000) estimates a seven-year lifetime for dictation equipment. We examined shipment data of dictation equipment from ITIC (2000) from 1994-1999 (and assuming the Y1993 data equaled the 1994 shipments of each) to estimate the stock, as shown in Table A-1.

Table A-1: Dictation Equipment Shipment Data and Stock Estimates

Year	Portable	Desktop	Systems
1993	367,400	255,125	38,100
1994	367,400	255,125	38,100
1995	382,400	258,700	39,800
1996	391,200	259,200	40,500
1997	395,200	259,700	41,200
1998	399,200	160,200	41,900
1999	401,700	259,600	42,600
STOCK	2,704,500	1,707,650	282,200

We could not find any information in the general literature for dictation equipment energy consumption rates or usage patterns. Instead, we used nameplate wattage values for dictation equipment. Based on field work, we made the rough assumption that dictation equipment operated for an average of two hours per day and remained off otherwise. Our power, usage and total annual electricity consumption (AEC) estimates for dictation equipment are presented in Table A-2.

Table A-2: Dictation Equipment AEC Calculations

Equipment Type	Active Power, W	Off Power, W	"On" Hours, per Week	AEC, TW-h[164]
Portable	0.22[165]	0.0	10	0.000535
Desktop	0.60[166]	0.0	10	0.00031
System[167]	N/A	N/A	N/A	N/A

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[164] Batteries account for much of portable dictation equipment AEC.

[165] The lower range of the Philips Pocket Memo Series, the 398, draws >100mW, while the top-end 696 draws >220mW, but more detailed power consumption information was not available. http://www.speech.be.philips.com/ud/get/Pages/ad_home.htm .

[166] The Philips Desktop 720-through-730 series consume >600mW. http://www.speech.be.philips.com/ud/get/Pages/ad_home.htm .

[167] Data for dictation systems was not located.

Regrettably, product information for “System” dictation equipment was not located. In addition, the power draw data represent minimum power draws. Nonetheless, even if the power draw were ten times greater than our estimate and assumed that dictation systems consumed ten times more energy than desktop systems, total dictation equipment AEC would still remain negligible compared to other equipment. Thus, we excluded dictation equipment from further analysis.

A.2 Scanners

Scanner shipments have increased dramatically since 1995. Assuming that scanners have the same split of commercial-domestic stock as personal computers [168] yields an estimated commercial stock of 15 million scanners (Table A-3).

Table A-3: Scanner Shipment Data and Stock Estimates

Year	Total Sales, Millions of Units
1997	3.25
1998	5.60
1999	9.35
2000	13.95
TOTAL	32.2
Commercial Stock	15.1

Sources: Sales Data from ITIC (2000); four-year lifetime from National Safety Council (1999)

Meyer and Schaltegger (1999) offered the only information that we could find for both energy consumption and operational hours by mode (see Table A-4 for these data, as well as the AEC estimate). Based on the relatively low quantity of energy consumed by scanners, we decided not to analyze scanners in more detail. Nonetheless, in general, we believe that the energy consumed by scanners will grow appreciably as shipments continue to grow in the future (e.g., ITIC [2000] projects almost 40 million scanners shipped in 2005). We believe that the majority of this growth will likely occur in the residential sector.

Table A-4: Scanner AEC Calculations

Mode	Power Draw, W	Hours/Week
Active	150	2.0
Stand-By	15	29
Off	0	137
Total AEC, TW-h		0.58TW-h

[168] 47% commercial; see Table 5-2.

A.3 Electric Typewriters

Once stalwarts of the office workplace, sales and use of typewriters have declined consistently since the widespread penetration of PCs into the commercial workspace in the 1980s. Annual shipment data displayed in Figure A-1 (ITIC, 2000) reflect these trends, showing a consistent annual decline of about 5% since 1987.

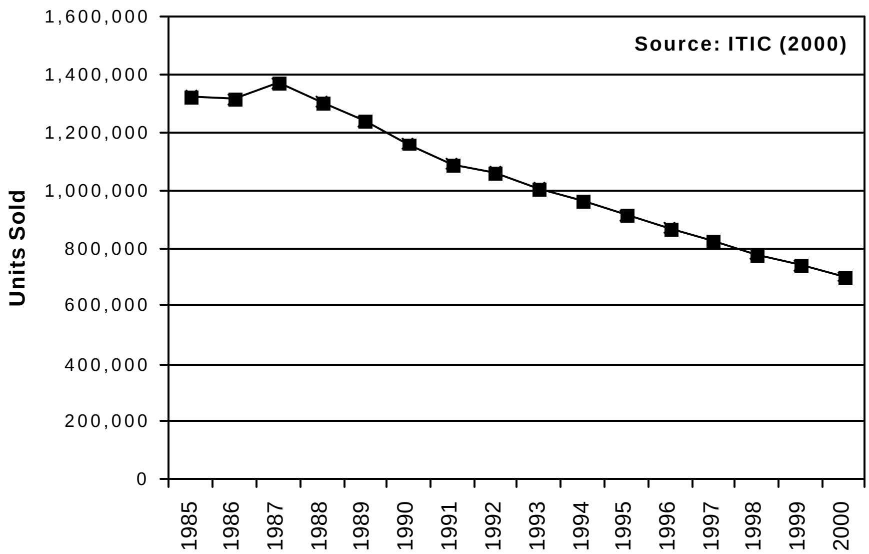

Figure A-1: Sales History of Electric Typewriters (from ITIC, 2000)

ADL (1993) investigated typewriter energy consumption for Y1990; Table A-5 contains their findings.

Table A-5: Summary of Typewriter AEC for Y1990 (from ADL, 1993)

Mode	Hours/Year	Power Draw, Watts
On	650	118
Standby	650	50
Typewriter Stock		11,100,000
Typewriter AEC, TW-h		1.2TW-h

In light of the downward trend in electric typewriters sales and decreased utilization of typewriters, the above estimate may be high. In any case, typewriters have a relatively low AEC and we expect that they will continue to decline in usage. For these reasons, electronic typewriters were excluded from further study.

A.4 Desktop Calculators

Desktop calculators, essentially electric adding machines, often include a small printer that generates a cash register-style output. ITIC (2000) shipment data, combined with a seven-year lifetime (Appliance Magazine, 2000) and an assumption that all shipments contribute to the commercial stock, yield the commercial stock estimate presented in Table A-6.

Table A-6: Desktop Calculator Shipment Data and Stock Calculation

Year	Total Sales (Millions of Units)
1994	13.60
1995	12.05
1996	11.64
1997	11.27
1998	10.89
1999	10.53
2000	10.19
TOTAL	80.2

The 80.2 million unit stock estimate appears high, as it translates into more than one desktop calculator for every two workers (all professions). Table A-7 summarizes the usage and power estimates. The AEC values, likely quite high, are still low relative to many other equipment types. Desktop calculator shipments are also declining, suggesting that their stock and usage will decline in the future and, as such, eliminated them from further analysis.

Table A-7: Desktop Calculator AEC Calculations

Mode	Power, W	Hours/Week	Source
On	20	20	Power: One-half 40W nameplate rating of Sharp EL-2630II; ADL estimate for hours (conservative).
Off	0	148	ADL Estimate
Total AEC, TW-h		1.7TW-h	

A.5 Hand-Held Calculators

Many calculators run on solar power and those that use batteries consume minimal amounts of power. We made the assumptions contained in Table A-8 to calculate an upper-bound energy consumption estimate for hand-held calculators in commercial buildings.

Table A-8: Hand-Held Calculator AEC Calculations (Upper Bound)

Data Type	Value	Source
Equipment Lifetime	5 Years	ADL Estimate
Shipments over Lifetime	108.6 Million	ITIC (2000)
“ON” Power Draw	0.0004 W	Nameplate rating of Sharp Scientific Calculator
Hours “ON”/Week	10 Hours	Estimate
Hours “OFF”/Week	158 Hours	Estimate
AEC, TW-h	23×10^{-6} TW-h	

We declined to study handheld calculator energy consumption further.

A.6 Wireless Phones

Wireless, or cellular, phones became commonplace during the 1990s. Battery-powered, compact and designed to maximize their time of operation without recharging, they consume energy at very low levels. Pottorf and Vyas (2000) estimate that in Y2000 there were 27,756,000 business subscribers to cellular, PCS, and hybrid systems, which implies a similar installed base of wireless telephones. Table A-9 presents wireless phone energy consumption parameters, applying power draw[169] and usage data from Meyer and Schaltegger (1999).

Table A-9: Wireless Telephone AEC Calculations

Operational Mode	Power Draw, W	Hours/Week in Mode	Source
Charging (phone in cradle)	3 Watts	56	Meyer and Schaltegger (1999)
Not Charging (cradle empty)	1.5 Watts	112	Meyer and Schaltegger (1999)
	AEC, TW-h	0.49TW-h	

Wireless telephone energy consumption was not analyzed in further detail due to the low AEC value.

[169] By measuring power draw at the cradle, Meyer and Schaltegger take into account the efficiency of the charging process.

A.7 Automated Teller Machines (ATMs)

Automated teller machines come in two distinct forms: full function and cash dispenser units. The full function units usually reside at banks and dispense cash and accept deposits, whereas cash dispensers are found at a variety of locations (convenience stores are the most prevalent) where they only dispense cash. A-10 presents ATM energy consumption values from Meyer and Schaltegger (1999) and U.S. ATM manufacturers.

Table A-10: Automated Teller Machine (ATM) Power Draw Data

Model	Power, Dispensing, W	Power, Idle, W	Source
Diebold 1062ix (Full Function Unit)	585	475	Nemens (2000)
Diebold 1064ix (Cash Dispenser Only)	250	150	Nemens (2000)
Triton 9600-Series (Cash Dispenser)	250 (Average Value)	250 (Average Value)	Jackson (2000)
Unknown machine type (Appears to be Full Function Unit)	357	283	Meyer and Schaltegger (1999)
Estimated Power: Full Function Unit	471	379	Average of Nemens and Meyer and Schaltegger
Estimated Power: Cash Dispenser Unit	250	200	Average of Nemens and Jackson

To represent the diversity of the ATM stock, we used an average of the above power draw levels for our energy consumption estimate. Nemens (2000) estimates an installed base of about 300,000 automated teller machines. All (2001) confirmed the stock and estimated, based upon recent sales break-downs from major industry players, that cash dispensers represent roughly 110,000 of the ATM stock. The stock, combined with the energy consumption by mode data of Meyer and Schaltegger (1999) displayed in Table A-11, show that ATMs consume approximately 0.85TW-h of electricity per annum.

Table A-11: Automated Teller Machine (ATM) AEC Calculations

Quantity	Value
Stock	300,000 Units
Full-Service ATM	190,000 Units
Cash Dispenser	110,000 Units
Hours/Day, Active	3.4 Hours
Hours/Day, Idle	21.6 Hours
TOTAL	0.84TW-h

Considering the rather low AEC of ATMs, we did not study them further.

A.8 Point-of-Service (POS) Terminals

Point-of-Service (POS) terminals represent a significant portion of the energy consumed by office and telecommunications equipment in retail buildings. They often incorporate a computer processor, which is typically of the Pentium class.

Table A-12 displays POS shipment data and stock estimates, based on a four-year equipment lifetime suggested by industry sources (Dower, 2001)[170] and Koomey et al. (1995).

Table A-12: Point-of-Service (POS) Terminal Shipment Data and Stock Estimates

Year	Shipments (thousands)	Source
1997	1,318	Bank Network News (2000)
1998	1,537	Bank Network News (2000)
1999	1,630	Bank Network News (2000)
2000	2,300	Haas (1998)
TOTAL Stock	6,785	

Unfortunately, we could not locate measurements of POS terminal power draw. Instead, we relied upon product literature information from equipment vendors. Recent developments, such as the incorporation of liquid crystal displays (LCDs) have tended to decrease the power draw relative to earlier units. Even CRT-based units, such as the IBM SureOne, draw less power than earlier vintage POS terminals. In addition, some POS terminals have begun offering a sleep mode that automatically reduces power when the unit is not in use (e.g., the Fujitsu/ICLTeamPoS 5000[171]). Table A-13 reports the power draw of current vintage POS terminals relative to the older models cited in Koomey et al. (1995).

[170] Dower (2001), a Boston-area POS dealer, estimated thatPOS terminals have a three- to five-year lifetime.

[171] See Fujitsu product literature at: http://www.fujitsu.com.au/products/retail/pos.htm .

Table A-13: POS Power Draw Data

Machine	Active Power, W	Standby Power, W	Comments and Source
IBM 4614 SureOne	N/A	38 – 48 (reading HDD)	Standard system with 9-inch monochrome or 10.5-inch color CRT monitor; 266MHz processor; ethernet and RS-232 connectivity[172]
NCR 7448	50[173]		300MHz processor, integrated cache and video support; 10.4" Color or Monochrome LCD; ethernet, RS-232, and USB connectivity; magnetic stripe reader[174]
Circa 1985 POS	130	130	Koomey et al. (1995)
1993 + later "Advanced"	70	10	Koomey et al. (1995); projection, includes LCD screens

Table A-14 presents the power levels used for the AEC calculation, as well as POS Terminals' AEC.

Table A-14: Point-of-Service (POS) Terminal AEC Calculations

Operational Mode	Power Draw, W	Hours/Week in Mode
Active Power Draw, W	50 Watts	35
Standby Power Draw, W	50 Watts	49
	AEC, TW-h	1.5TW-h

Although POS terminals represent a significant portion of office equipment energy consumption in commercial retail establishments, we excluded them from further study due to their relatively low overall AEC.

A.9 Modems/Remote-Access Servers (RAS)

Modems provide remote access to a computer network. A remote-access server (RAS) is a box containing a group of modems along with the associated line interfaces and routing capabilities. For example, when a person accesses the Internet via a dial-up modem, their modem contacts their Internet service provider (ISP) and connects into the ISP's internal network via a modem housed in a RAS.

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[172] See http://www2.clearlake.ibm.com/store/product/html/4614.html .

[173] Power supply rated 100-120V at 0.8A, which translates into a maximum of 96W; assuming that it regularly runs at 50% of the rated power suggests a power draw closer to 50W.

[174] See NCR Product Information, found at: http://www.ncr.com/products/hardware/sa_7448_ts.htm .

Modem and RAS stocks have increased dramatically over the past five years due to the tremendous growth of Internet usage over that time period. We derived the modem stock estimates by vintage shown in Table A-15 from household Internet penetration and our estimates of the number of modems deployed per subscriber.

Table A-15: Modem Stock by Vintage

Year	Internet Subscribers (Thousands)[175]	Users per Modem Ratio[176]	New Households (Thousands)	Modems Needed (Thousands)	Fraction in Service in 2000[177]	Modems in Service, 2000 (Thousands)
1992	1,000	-----	-----	-----	-----	-----
1993	1,500	20	500	25	20%	5
1994	3,000	20	1,500	75	40%	30
1995	5,700	18	2,700	150	60%	90
1996	8,600	16	2,900	181	80%	145
1997	12,900	14	4,300	307	90%	276
1998	19,300	12	6,400	533	95%	507
1999	27,500	12	8,200	683	100%	683
2000	43,600	12	16,100	1,342	100%	1,342
				Modem Stock	(Thousands)	3,078

While modem stocks have risen, modem energy consumption has decreased dramatically over the past five years. For example, the modems deployed circa 1995 consumed approximately 10W per modem. Currently, modems at ISPs are typically integrated into rack-mounted RAS units with large quantities of modems per rack. For example, the Nortel CVX1800 RAS (described in Table A-16) incorporates 1344 modems and consumes ~1W/modem. Table 4-20 also summarizes average modem power consumption by vintage, and, assuming 24-hour operation, modem/RAS AEC.

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[175] Compiled from several issues of "The Internet Data Services Report", by Morgan Stanley and other sources; 20% added to account for non-residential subscribers.

[176] ADL Estimate, based upon prior industry work.

[177] ADL Estimate, based upon prior industry work.

Table A-16: Modem / Remote-Access Server Power Draw and AEC

Year	Estimated Mean Power Consumption/Modem, W	Representative Equipment Used for ADL Power Consumption Estimates
1993	10	N/A
1994	8	N/A
1995	7	Ascend MAX 4000: Rated 800W for 48 modems
1996	6	N/A
1997	5	Ascend MAX6000: Around 500W, 72 modems; Xylogics: ~500 modem shelf at ~4W/modem.
1998	3	N/A
1999	1.5	Nortel CVX1800: Rated Power of 7A at 48V(DC) for 1344 modems.
2000	1	Digital Networks: 48-Modem RAS rated 30W; Nortel CVX1800: Rated Power of 7A at 48V(DC) for 2688 modems; Nortel CVX600 rated "0.5 kW max", for 612 modems.
	TOTAL AEC, TW-h	0.06

Taken together, modems consume relatively small quantities of energy that should not change appreciably over the upcoming years. The continued growth in Internet access rates (total quantity of modems) will be offset by the decreased energy consumption per modems as newer modems replace older modems which are an order of magnitude more inefficient. In addition, many Internet connections will move to “always-on” broadband-access technologies (such as cable modems and phone-based DSL) that consume more energy than modems/RASs. Thus, the total number of modems in service is likely to peak and then begin to decline before 2005. As such, we decided not to explore modem energy consumption further.

A.10 Facsimile Machines

We used the ITIC (2000) facsimile machine shipment data over the five-year equipment lifetime estimated by Appliance Magazine (2000) to develop the total facsimile machine stock estimate presented in Table A-17. The commercial-residential stock split came from residential facsimile machine saturation data from CEA (2001).

Table A-17: Facsimile Machine Shipment Data and Stock Estimates

Year	Shipments (Thousands of Units)	Commercial Stock Estimate (Thousands of Units)
1996	4,750	3,658
1997	5,350	4,120
1998	5,992	4,614
1999	6,650	5,120
2000	7,357	5,664
TOTAL Commercial Stock		23,176

As summarized in Table A-18, several researchers have published results for facsimile machine power draw by operational mode. Facsimile machines have three basic operational modes: "Active", while sending or receiving a facsimile, "Stand-by" while ready to receive or send a facsimile, and "Off" when manually turned off.

Table A-18: Facsimile Machine Power Draw Data by Mode

Source	Active Mode, W	Stand-By Mode, W	Off Mode, W	Notes
Wilkins and Hosni (2000)	30	15	0	
Komor (1997)	175	35	N/A	Power draws from Piette et al., 1995
Meyer and Schaltegger (1999)	11.4/106[178] (Laser) 10.6/14 (Ink-Jet)	9.6 (Laser) 6.5 (Ink-Jet)	N/A	
Kawamoto et al. (2000)	N/A (See note)	15	0	No active mode; included printing energy separately

We used the power consumption data of Wilkins and Hosni (2000), combined with the weekly active power mode measurements of Meyer and Schaltegger (1999) and an assumption that facsimile machines are perpetually on, to calculate the facsimile machine AEC (Table A-19).

[178] Sending/Receiving, i.e., laser facsimile machines draw 11.4W while sending and 104W while receiving (printing).

Table A-19: Facsimile Machine AEC Calculations

Operational Mode	Power Draw, W	Hours/Week in Mode
Active	30	0.5 + 0.7[179]
Stand-by	15	166.8
Off	0	0
	AEC, TW-h	3.1TW-h

Although facsimile machines do represent a distinct portion of the total energy consumed by office and telecommunications equipment, we decided not to analyze them further for three reasons:

1. Many devices consume more energy than facsimile machines.

2. Future energy consumption by facsimile machines will likely be flat, because:

   - Facsimile machines have realized a high commercial market penetration;

   - Facsimile machines are becoming more efficient, consuming,11.2W on average in stand-by mode (ENERGY STAR® Homepage, from Kawamoto et al., 2001), ENERGY STAR® facsimile machines dominate the current sales (~95%, from LBNL, 2000), and lower-power ink-jet facsimile machines lead the current market, with 38% of unit sales in 2000 (compared to 30% for laser units; Davidson, 2000); and,

   - We believe that electronic data transfer will ultimately usurp much of the traffic currently transmitted by facsimile machines.

3. A number of researchers have already studied facsimile machine energy consumption.

A.11 Smart Hand Held Devices

Sales of hand held devices, such as the Palm Pilot™, grew vigorously during the late 1990s. The annual sales estimates in Table A-20 for smart handheld devices come from House and Hwang (1999). We assumed that hand held devices have a three-year lifetime, the same as PCs, and that 67% of the stock resides in commercial buildings.

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[179] 0.5 hours sending and 0.7 hours receiving per week.

Table A-20: Hand Held Device Shipment Data and Stock Estimate

Year	Shipments
1998	3,364,000
1999	3,638,000
2000	5,302,000
TOTAL Stock	12,304,000
Commercial Stock	8,244,000

Hand held devices operate on either re-chargeable or disposable batteries, which translates into very low power consumption levels. For example, Compaq's iPAQ H3600 Series Pocket PC used a 950 mAh Lithium Polymer battery which, over the 12-hour continuous-use lifetime, translates into a power draw of 0.079W[180]. Additional attachments, such as wireless ethernet or modem cards, can increase power consumption levels substantially. Furthermore, the small battery chargers used to recharge the device batteries are quite inefficient, likely on the order of 25%, increasing the power draw of the devices by a factor of ~4. We assumed that all devices run on re-chargeable batteries and specifically selected the very aggressive estimate usage shown in Table A-21 to attempt to place an upper bound on the energy consumption of handheld devices.

Table A-21: Smart Hand Held Devices AEC

	Power Draw, W	Hours/Week (ADL Estimates)	Power Draw Source
On	0.079	56	Compaq iPAQ H3600 Series[181].
Sleep	0.015	28	Handspring Visor Series[182]
Off	0	84	Estimate
AEC, TW-h	0.008TW-h	Reflects estimated ~25% battery re-charging efficiency	

Relative to other devices, smart handheld devices consume a minimal amount of energy and as such, do not warrant further study.

[180] See http://www5.compaq.com/products/handhelds/pocketpc/H3650.html .

[181] 950mA Lithium-polymer battery lasts 12 hours continuously on; 14 hours for "typical" use (www.compaq.com).

[182] The Visor developer technical information page (http://www.handspring.com/developers/tech_faq.jhtml) mentions that the LCD screen consumes more than 60% of the unit's power, about 25mW, implying a 0.04mW draw in "ON" mode, and 0.015mW in "Sleep" mode.

A.12 Cable Modems Termination Systems (CMTSs)

Cable modems enable computers to realize broadband access to the Internet via the cable television (CATV) cables used also to provide CATV access. Although the cable modems themselves reside in residences, the Cable Modem Termination Systems (CTMS) reside at the origin of the CATV companies' CATV signals and, due to their "always on" connectivity, continuously draws electricity. Each CMTS aggregates information flowing to and from up to several hundred subscribers to the Internet, delivering cable modem service at the head end, which, separately for each subscriber, modulates data onto a reserved TV channel. This allows the cable Internet service and cable TV video to share the HFC distribution, which usually originates from the broadcast airwaves and satellites.

Table A-22 presents energy consumption calculation for cable modems. To estimate the national energy consumption by cable modems, we obtained the number of cable modem subscribers and considered it in the context of typical CMTS equipment.

Table A-22: Cable Modem Termination Systems (CMTS) AEC Calculation

Quantity	Value	Source
Number of Cable Modem Subscribers in U.S., Thousands	2,400	NTIA (2000)[183]
CMTS Energy Consumption per Subscriber, Watts	1 Watt[184]	Cisco uBR7246 Cable Modem Head End
Operational Hours/Week	168 Hours	ADL Estimate ("Always On")
TOTAL Energy Consumption, TW-h	0.021TW-h	

Less than 5% of U.S. households in Y2000 had broadband Internet access (NITA, 2000), indicating the potential for huge growth in the number of cable modems. In the context of telecommunications equipment, much greater market share (~50% of households) and their "always on" nature suggests that they could potentially represent a non-trivial portion of telecommunications energy consumption. In the context of office and telecommunications equipment, however, cable modems should remain a minor energy consumer and thus did not receive further study.

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[183]43.6 million households have Internet access, of which 10.7% had broadband Internet access; broadband breakdown: 50.8% cable modem, 33.7% DSL, 15.5% other.

[184]ADL estimate, based upon the Cisco uBR7246 is a common cable modem head ends (CMTS), combining the cable modem with router function. A few can fit into one rack. It has a 550 W rated power supply, and should fuse at 7A AC or 14A DC, suggesting a steady-state consumption of around 300-400W. Each one supports four cable modem cards, i.e., four "nodes", each of which supports about 100 subscribers. The actual number of subscribers/node is up to the CATV company and can go up to 200. In practice, CATV companies operate at lower numbers of subscribers to maintain service quality, i.e., high bandwidth.

A.13 Voice Mail Systems (VMSs)

Voice mail systems (VMSs) receive, store, and distribute voice messages. In the past, voice mail systems consisted of computers linked to storage drives. Current voice mail systems usually consist of a single computer which stores messages for all personnel at a given site or racked computers that handle larger quantities of voice mail for voice messaging services. Voice mail systems continue to grow in capacity (greater quantity of messages and people per system) while shrinking in size. Consequently, the energy consumption of voice mail systems varies significantly with vintage. To estimate the total energy consumption of voice mail systems, we obtained the number of private voice mail subscribers and then estimated the energy consumption of representative systems on a Watts/subscriber basis (see Table A-23).

Table A-23: Voice Mail System AEC

Quantity	Value	Source
Number of Voice Mail Subscribers	74,000,000	MMTA (2000)
Power Draw/Subscriber	0.3 W	Octel Aria 250, 48-Port VMS, serving ~1,400 people, draws labeled 7A, 120V, Maximum
Operational Hours, Week	168 Hours	ADL Estimate
TOTAL AEC, TW-h	0.19TW-h	

A quick check confirms the order-of-magnitude of the earlier Power Consumption per Subscriber estimate. Assuming that a VMS is very similar to a PC-class server, it can be implemented using 24-port (T1) PCI cards that draw ~12W apiece[185] that feed a few disk drives. Combined with a PC server drawing 100W, this translates into approximately 125W, or about 0.1W/subscriber. Very low annual electricity consumption led us to exclude voice mail systems from further study.

A.14 Very Small Aperture Terminals (VSATs)

Very small aperture terminals (VSATs) are devices featuring parabolic dishes of less than 3 meters in diameter that provide communication via uplinks to satellites at data rates ranging from 56kb to 2Mb per second. Typically, large hubs (dishes,

[185] For example, the 11-watt Dialogic D240SC-T1, or the dual-T1 D480SC-2T1 that takes about 20 watts, or the 22-watt 4E1 (120 port) DM/V600-4E1

receiver, and transmission equipment) send information from a central location (e.g., a corporate headquarters) to a satellite, which then sends the information to the individual VSATs; similarly, VSATs send information back to hubs via satellites. For example, a drug store chain may use a VSAT to communicate information to and from individual stores to its corporate headquarters. In this instance, communications may include information about a prescription with insurance companies or its headquarters, credit card transactions, sales and stocks, and the music heard in the store. Other major users of VSATs include automobile dealerships, department stores, and gasoline station chains.

Based upon consultation with Maul (2001), we estimated the AEC of VSATs and the large hubs separately. He provided an estimate of device power draws, as well as the installed of the hubs; the VSAT stock estimate comes from Comsys (2001) (see Table A-24). VSATs are on around the clock, although some do enter a lower-power mode during periods of inactivity.

Table A-24: Very Small Aperture Terminal (VSAT) AEC

Characteristic	VSATs	Hubs
U.S. Stock, Units	265,000[186]	50
Power Draw, Watts	100W[187]	2,000W
Operational Hours/Week	168	168
Total AEC, TW-h		0.23TW-h

As the AEC for VSATs was small, we did not analyze VSATs further.

[186] COMSYS (2001) estimates a global stock of ~390,000 in 1999; North America accounts for ~70% of the global market, the U.S. ~97% of the North American market.

[187] Reflects the average value over a range of 25 to 150W.

Appendix B: Unit Electricity Consumption (UEC) Data

Table B-2 shows the break-down of unit energy consumption (UEC) for all equipment types studies, by mode. All modes are consistent with the mode definitions in Section 4.1.2; Table B-1 repeats them here for the sake of clarity.

Table B-0-1: Office Equipment Usage Modes

Mode Type	Description	Example
Active	Device carrying out intended operation	• Monitor displays image • Copier printing
Stand-By	Device ready to, but not, carrying out intended operation	• Monitor displays screen saver • Copier ready to print
Suspend	Device not ready to carry out intended operation, but on	• Monitor powered down but on • Copier powered down but on
Off	Device not turned on but plugged in	• Monitor off, plugged in • Copier off, plugged in

Table B-0-2: Device Unit Energy Consumption (UEC) Values, by Mode

Equipment Type	Total UEC (kW-h/year)	UEC by mode (%)			
		Active	Standby	Suspend	Off
Monitors	333	89%	0%	8%	3%
PCs – Desktop	297	96%	0%	3%	2%
Copiers	1,077	2%	74%	21%	3%
UPSs	429	100%	0%	0%	0%
Laser Printers	694	27%	61%	12%	0%
Server - Low End	1,095	100%	0%	0%	0%
General Display	264	76%	0%	21%	3%
Server – Workhorse	5,694	100%	0%	0%	0%
LAN Switch (per port)	35	100%	0%	0%	0%
Facsimile Machine	132	1%	99%	0%	0%
Cell Site Equipment (per site)	23,214	100%	0%	0%	0%
Server Mid Range	10,731	100%	0%	0%	0%
Workstations	720	96%	0%	3%	1%
Transmission (Phone) (per terminal)	1,752	100%	0%	0%	0%
Desktop Calculators	21	100%	0%	0%	0%
Hubs (per port)	11	100%	0%	0%	0%
Data Storage (per Terabyte)	4,199	100%	0%	0%	0%
POS Terminals	219	42%	58%	0%	0%
Typewriters	109	70%	30%	0%	0%
Routers (per device)	350	100%	0%	0%	0%

Public Phone Network (per line)	6.0	100%	0%	0%	0%
Private Branch Exchange (per subscriber)	17	100%	0%	0%	0%
ATMs	2,955	16%	84%	0%	0%
Inkjet Printers	92	3%	92%	0%	6%
Scanners	38	41%	59%	0%	0%
Wireless Phones	18	50%	0%	50%	0%
VSATs (per device)	876	100%	0%	0%	0%
Impact Printers	121	12%	86%	0%	2%
PCs – Laptop	32	43%	0%	39%	19%
Server - High-end	22,075	100%	0%	0%	0%
Supercomputers	1,746,659,000	100%	0%	0%	0%
Voice Mail Systems (per subscriber)	2.6	100%	0%	0%	0%
Line Printers	1,498	100%	0%	0%	0%
Other Printers	285	3%	96%	0%	1%
WAN Switches (per device)	3,066	100%	0%	0%	0%
Modems / RAS	20	100%	0%	0%	0%
CMTS (per subscriber)	8.8	100%	0%	0%	0%
Smart Handheld Devices	0.3	91%	0%	9%	0%
Dictation Equipment	0.2	100%	0%	0%	0%
Handheld Calculators	0.0	100%	0%	0%	0%
Weighted AEC Totals, by Mode		77%	16%	5%	2%

Overall, the "active" mode accounts for more than 75% of commercial office and telecommunications equipment AEC. Similarly, most equipment types consume a majority of energy in the "active" mode. Copiers (2%) and printers (3 to 27%) are notable exceptions; the "standby" mode accounts for the bulk of their AEC.

Appendix C: Magnetic Disk System Storage Power Draw Data

To calculate total disc storage energy consumption, we retrieved information on power draw for equipment typically installed in each of the three years. Table C-1 lists representative magnetic disk drives and their corresponding power draw. Nine to ten GB disk drives were common in 1997, 18-20 GB drives in 1998, and 30-40 GB drives in 1999.

Table C-1: Magnetic Disk System Storage Power Draw Data

Memory, (GB)	Vendor	Idle Power, (W)	Adjusted Power[188] w/15% increase due to active status, (W)	Power Consumption Efficiency, (W/MB)
9.1	Western Digital	10.6	12.2	0.00134
9.1	IBM 36 LXZ SCSI	8.5	9.8	0.00107
9.1	38 LXZ FC-AL	9.9	11.4	0.00126
9.1	36LP SCSI	7.2	8.3	0.00091
9.1	73LXZ SCSI	6.7	7.7	0.00085
9.1	73LXZ FC-AL-5	8.7	10.0	0.00110
9.1	Quantum Atlas 10K	8	9.2	0.00101
10	Fireball Ict23	5	5.8	0.00058
18.2	Quantum Atlas 10K	10	11.5	0.00063
18.3	Western Digital	9.2	10.6	0.00058
18.3	IBM 36 LXZ SCSI	9.7	11.2	0.00061
18.3	37 LXZ FC-AL	10.5	12.1	0.00066
18.3	36LP SCSI	7.9	9.1	0.00050
18.3	73LXZ SCSI	6.7	7.7	0.00042
18.3	73LXZ FC-AL-4	8.7	10.0	0.00055
18.4	Atlas 10K III	7.5	8.6	0.00047
20	Fireball Ict22	5	5.8	0.00029
30	Fireball Ict21	5	5.8	0.00019
36.4	Quantum Atlas 10K	15.5	17.8	0.00049
36.7	IBM 36 LXZ SCSI	12.9	14.8	0.00040
36.7	36 LXZ FC-AL	13.6	15.6	0.00043
36.7	73LXZ SCSI	7.4	8.5	0.00023
36.7	73LXZ FC-AL-3	9.4	10.8	0.00029
36.7	Atlas 10K III	9.5	10.9	0.00030
36.9	36LP SCSI	9.0	10.3	0.00028
40	Fireball Ict20	5	5.8	0.00014

[188] Adjusted power draw is 115% of the idle power draw and is necessary to account for periods of active reading. In idle mode the disks are spinning but not reading. It is assumed these drives operate at the adjusted level 8,760 hours per year.

Appendix D: Office Paper Consumption

Kawamoto et al. (2001) noted the difficulty in obtaining accurate and representative annual usage times in the “active” mode for printing devices, as well as reliable power draw numbers for the “active” duration. Instead, they estimate the “active” mode energy consumption for laser printers, facsimile machines and copy machines by calculating the images copied in one year for each device type and multiplying that by the approximate energy consumption per image.

We decided to take the same approach to estimating “active” mode energy consumption for laser printers and copy machines. The first section of this Appendix explains how we apportioned paper consumption between the different devices and calculated the number of images produced by each equipment type. The second section develops printing energy consumption estimates based upon the image quantities generated in the first section.

D.1 Paper and Image Consumption

Our methodology relies upon determining the number of office bond paper[189] sheets consumed in the U.S. in Y2000, and then apportioning that total paper consumption between the copiers, printers and facsimile machines. We use a different source to estimate the number of sheets consumed by roll-fed laser printers because they do not use office bond paper. We convert the number of sheets into the number of images by apply duplexing rates reported in the literature.

D.1.1 Office Bond Paper Consumption

We estimated the total number of writing bond paper sheets produced in Y2000 by dividing the estimated total weight of office bond paper consumed in Y2000, 5,481,000 U.S. tons (based upon interpolation of data from Miller Freeman, 1999 and Fredonia Group, 2000[190]) by the approximate weight of one sheet of paper, 5 grams[191]. Second, we assumed that all 9.95×10^{11} sheets of paper produced in Y2000 were consumed in Y2000.

Three types of office equipment consume office bond paper: sheet-fed printers, facsimile machines and copy machines. In order to calculate the number of images

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[189] Specifically "Uncoated Free-Sheet Paper", "Bond and Writing" grades for "Office Reprographic" end use.

[190] Using production data for 1998 and projections for Y2003 production, we assumed a steady compound annual growth rate over that period to estimate Y2000 production in tons. Based upon Kendall (2001), we added an additional 5% to the domestic paper production numbers to account for imports.

[191] 2,000 sheets of 8-1/2" x 11" copy paper equals one ream of paper, and the copy paper "benchmark basis weight" is 20 lbs./ream. So (20 lbs./ream)*(1 ream/2000 sheets) *(454 g/lb.) = 4.54 grams/sheet. In addition, 24 lbs./ream is also common (5.45 g), so 5 grams likely represents a good estimate of the average sheet weight.

produced, we first had to allocate paper consumption by equipment type, taking into account the range of annual copies per machine of each speed band.

D.1.2 Laser Printers

Su (1999) contains survey-based estimates and projections of images produced by laser printers in commercial buildings, exhibited in Table D-1, and we use these data to calculate the number of images and sheets of paper consumed in Y2000[192] by laser printers. According to Su (2001), 50% of the 70-99 ppm and 100% of the 100+ ppm machines are roll fed machines, whose paper is not included in the office bond paper and requires independent accounting. Fortunately, Su (1999) also provides an estimate of roll-fed laser printer print volumes in Y2000 (see Table D-1).

Table D-1: Paper Consumption by Device Type, from Su (1999)

Type	Paper Consumption, millions of sheets
Sheet Fed Commercial Laser Printers	608,325
Roll Fed Printers[193]	496,731
Inkjet Printers	165,100

Table D-2 summarizes the annual laser printer image production estimates, broken down by printer technology (from Su, 1999). As indicated by Su (2001), laser printers in the highest-speed bands (70+ppm) often use duplex capabilities; for these devices, we assume the duplex rate is equal to the 30% assumption used by Kawamoto et al. (2001).

[192] We assume that printers do not use duplex capabilities (i.e., the number of images equals the number of sheets of paper).

[193] Each page is 8.5-inch by 11-inch piece of paper; assumes a duplex rate of 30% (ADL Estimate, based upon Kawamoto et al., 2001).

Table D-2: Break-Down of Commercial Laser Printer Image Volumes, by Printer Feed Type

Printer Type, by speed	Percent of roll fed machines in class, from Su (2001)	Duplex Rate[194]	Total Sheets Printed, millions/year	Total Images Printed, millions/year
<8ppm	0%	0%	1,070	1,070
8–12ppm	0%	0%	14,605	14,605
13–20ppm	0%	0%	368,400	368,400
21–29ppm	0%	0%	72,600	72,600
30–45ppm	0%	0%	70,100	70,100
46–69ppm	0%	0%	55,100	55,100
70–99ppm	50%	30%	21,142	23,900
100+ppm	100%	30%	487,539	633,800
Desktop Color Laser	0%	0%	14,500	14,500
		TOTALS	1,105,056	1,254,075

D.1.3 Copiers

To estimate the total number of sheets of paper consumed by copiers, we subtracted the total number of paper sheets consumed by non-roll fed printers in Section D.1.2 from the total number of paper sheets consumed in Y2000 (154 billion sheets of paper). This methodology explicitly neglects the small portion of paper consumed by facsimile machines as well as any devices in residences[195], and results in an upper bound copier paper consumption estimate.

Most copiers have duplexing capabilities and we used the duplexing rates, broken down by copier band, reported by Graff and Fishbein (1991, from Kawamoto et al., 2001) to calculate the number of copied images in Table D-3. Graff and Fishbein (1991) also estimated the number of sheets of paper a copy machine consumes per year for each copier band which, when multiplied by the stock, equals the number of sheets per year consumed by copier speed band. However, their data implies that copiers consumed about 860 billion sheets of papers, or more than five times the 154 billion sheet estimate derived earlier. Instead, we used the Graff and Fishbein data to determine the percentage of paper consumed by band of copier and allocate the total volume of copier paper consumed to each speed band. The product of the paper consumed by band multiplied by one plus the respective duplex rate yields the total number of images copied per year shown in Table D-3.

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[194] Kawamoto et al. (2001) for high-end printers; we assigned it solely to the roll-fed portion of the market.

[195] Kawamoto et al. (2001) estimate that facsimile machines consume 5% of all sheets of paper, and that residential office equipment consumes an additional 7.6% of total paper production.

Table D-3: Copy Machine Image Production and Paper Consumption

Copier Band	Copier Stock	Sheets/Machine (000s), from Graff and Fishbein (1991)	Sheets/Year Thousands [196]	% of Copier Paper Consumed by Band	Duplex Rate (Graff and Fischbein, 1991)	Number of Images Copied
Retail 1-16 cpm	372,920	1	372,920	0.04% [197]	0	6.7E+07
17-20 cpm	2,701,262	25	67,531,550	7.85%	2%	1.2E+10
21-30 cpm	3,240,251	66	213,856,566	24.9%	8%	4.1E+10
31-44 cpm	941,783	111	104,537,913	12.2%	14%	2.1E+10
45-69 cpm	1,359,332	141	191,665,812	22.3%	32% [198]	4.5E+10
70-90 cpm	262,936	465	122,265,240	14.2%	40%	3.1E+10
91+ cpm	98,479	1,620	159,535,980	18.6%	60%	4.6E+10
					Total Images Copied	2.0E+11

D.2 Electrostatic Imaging Energy Consumption

Table D-4 presents our estimate of the energy consumed by laser printers, roll-fed laser printers, and copy machines, assuming that each electrostatic print or copy consumes 1W-h of energy (Nordman, 1998; Kawamoto et al., 2001).

Table D-4: Image Production and Energy Consumption, by Device

Machine Type	Millions of Images Produced	Energy Consumption due to Image Production, TW-h
Laser Printer	608,325	0.61
Roll-Fed Laser Printers	645,750	0.65
Copy Machine	197,045	0.2
TOTAL AEC, Electrographic Processes, TW-h		1.46

For the sake of comparison, we calculated the energy consumed to manufacture the paper and present the results in Table D-5, even though this energy *is not consumed* by the office equipment and hence *not counted* in our device energy consumption estimates. We used a value of 15W-h per sheet of paper produced, noting that paper

[196] Applying Graf and Fishbein (1995) data for sheets per copier per year, broken down by copier band.

[197] Note that the very small percentage of paper consumed by retail copiers validates our assumption that residential copiers, assumed to be primarily retail copiers, consume a minute fraction of all paper consumed by copiers.

[198] An updated duplex rate from Nordman et al. (1998).

production consumes between 12 and 17W-h of energy (Nordman et al., 1998)[199]. Thus, producing paper consumes more than an order of magnitude more energy than used to print or copy onto the paper.

Table D-5: Energy Consumed to Manufacture Paper Consumed by Office Equipment

Machine Type	Paper Consumption, billions of sheets	Manufacturing Energy Consumed, TW-h
Laser Printer	608	9.1
Roll-Fed Laser Printers[200]	492	7.5
Inkjet Printers	19	0.3
Copy Machines	154	2.3
TOTAL AEC, Paper Production, TW-h		**19.2**

[199]Manufacturing a piece of paper from wood requires about 17W-h, one from recycled paper ~12W-h.

[200] This assumes that the production of roll-fed paper consumed the same amount of energy per sheet as bond paper.

Appendix E: UPS Stock Calculation Details

Tables E-1 and E-2 show the detailed breakdowns for the UPS sales in both $US and units, respectively. These estimates by year, device type, and power class reflect the data sources referred to in Section 5.7, i.e., Taylor and Hutchinson (1999) and Plante (2000), as well as the assumptions outlined in that section.

UNIT SALES

Year	Type	<0.5kVA	0.5-0.9kVA	1.0 - 2.9 KVA	3.0 - 5.0 KVA	5.1-20 kVA	21-50kVA	51-100kVA	101-200kVA	201-500kVA	>500kVA	TOTAL
1990	Stand-by	998,813										998,813
1991	Stand-by	1,103,689										1,103,689
1992	Stand-by	1,219,576										1,219,576
1993	Stand-by	1,347,632										1,347,632
1994	Stand-by	1,489,133										1,489,133
1995	Stand-by	1,645,492										1,645,492
1996	Stand-by	1,818,268										1,818,268
1997	Stand-by	2,009,187										2,009,187
1998	Stand-by	2,220,151										2,220,151
1999	Stand-by	2,638,501										2,638,501
2000	Stand-by	2,881,243										2,881,243
2001	Stand-by	3,146,317										3,146,317
2002	Stand-by	3,435,778										3,435,778
2003	Stand-by	3,751,870										3,751,870
2004	Stand-by	4,097,042										4,097,042
1990	Interactive	33,440	313,308	111,720	18,327	2,600	0	0	0	0	0	479,395
1991	Interactive	36,951	346,205	123,450	20,251	3,232	0	0	0	0	0	530,090
1992	Interactive	40,831	382,557	136,412	22,378	4,017	0	0	0	0	0	586,196
1993	Interactive	45,118	422,726	150,736	24,727	4,994	0	0	0	0	0	648,301
1994	Interactive	49,856	467,112	166,563	27,324	6,207	0	0	0	0	0	717,061
1995	Interactive	55,091	516,158	184,052	30,193	7,715	0	0	0	0	0	793,209
1996	Interactive	60,875	570,355	203,378	33,363	9,590	0	0	0	0	0	877,561
1997	Interactive	67,267	630,242	224,732	36,866	11,921	0	0	0	0	0	971,028
1998	Interactive	74,330	696,418	248,329	40,737	14,817	0	0	0	0	0	1,074,631
1999	Interactive	88,337	827,646	295,123	48,413	25,673	0	0	0	0	0	1,285,191
2000	Interactive	96,464	913,051	325,576	54,561	36,162	0	0	0	0	0	1,425,815
2001	Interactive	105,338	1,007,114	359,117	61,491	44,199	0	0	0	0	0	1,577,260
2002	Interactive	115,029	1,110,693	396,052	69,300	48,381	0	0	0	0	0	1,739,456
2003	Interactive	125,612	1,224,731	436,716	78,101	51,559	0	0	0	0	0	1,916,718
2004	Interactive	137,168	1,350,258	481,476	88,020	54,673	0	0	0	0	0	2,111,596
1990	On-Line	12,491	53,011	17,394	4,374	1,404	619	372	203	118	51	90,035
1991	On-Line	13,803	58,577	19,220	4,834	1,745	769	462	252	146	63	99,871
1992	On-Line	15,252	64,727	21,238	5,341	2,169	956	574	314	182	78	110,832
1993	On-Line	16,853	71,524	23,468	5,902	2,696	1,189	714	390	226	97	123,059
1994	On-Line	18,623	79,034	25,932	6,522	3,351	1,478	887	485	281	121	136,713
1995	On-Line	20,578	87,332	28,655	7,206	4,165	1,837	1,103	603	349	150	151,979
1996	On-Line	22,739	96,502	31,664	7,963	5,177	2,283	1,371	749	434	187	169,069
1997	On-Line	25,127	106,635	34,989	8,799	6,436	2,838	1,704	931	539	232	188,229
1998	On-Line	27,765	117,832	38,662	9,723	7,999	3,527	2,118	1,157	670	289	209,743
1999	On-Line	32,997	140,035	45,948	11,555	13,860	6,111	3,670	2,005	1,161	500	257,842
2000	On-Line	36,032	154,485	50,689	13,023	19,523	8,609	5,169	2,825	1,635	705	292,695
2001	On-Line	39,347	170,400	55,911	14,677	23,862	10,522	6,318	3,453	1,999	861	327,349
2002	On-Line	42,967	187,926	61,661	16,541	26,119	11,517	6,915	3,779	2,188	943	360,557
2003	On-Line	46,920	207,220	67,992	18,641	27,835	12,274	7,369	4,027	2,331	1,005	395,616
2004	On-Line	51,237	228,459	74,961	21,009	29,516	13,015	7,815	4,271	2,472	1,066	433,820
TOTALS, NA STOCK		13,897,465	5,183,565	1,819,049	329,375	174,404	30,216	18,142	9,915	5,739	2,474	21,470,344

	Stock	<0.5kVA	0.5-0.9kVA	1.0 - 2.9 KVA	3.0 - 5.0 KVA	5.1-20 kVA	21-50kVA	51-100kVA	101-200kVA	201-500kVA	>500kVA
TOTAL STOCK	Stand-by	13,212,841	0	0	0	0	0	0	0	0	0
	Interactive	442,364	4,153,871	1,481,190	244,132	105,879	0	0	0	0	0
	On-Line	242,260	1,029,694	337,859	85,243	68,525	30,216	18,142	9,915	5,739	2,474

	Stock	<0.5kVA	0.5-0.9kVA	1.0-2.9kVA	3.0-5.0kVA	5.1-20kVA	21-50kVA	51-100kVA	101-200kVA	201-500kVA	>500kVA
IT/Telcom STOCK IN US	Stand-by	8,324,090	0	0	0	0	0	0	0	0	0
	Interactive	278,689	2,616,939	933,150	153,803	66,704	0	0	0	0	0
	On-Line	152,624	648,707	212,851	53,703	43,171	19,036	11,430	6,246	3,616	1,558

Figure E-1: UPS Unit Sales, by Device Type, Power Class and Year

Year	North America UPS Shipments, Millions $US	TOTAL, <5kVA	<0.5kVA	0.5-0.9kVA	1.0 - 2.9 KVA	3.0 - 5.0 KVA	5.1-20 kVA	21-50kVA	51-100kVA	101-200kVA	201-500kVA	>500kVA
1990	563	482	96	140	164	82	27	13	10	10	11	9
1991	633	533	107	155	181	91	33	16	13	13	14	11
1992	713	589	118	171	200	100	41	20	16	16	17	14
1993	806	651	130	189	221	111	51	25	20	20	22	17
1994	911	719	144	209	244	122	64	31	25	25	27	21
1995	1,034	795	159	230	270	135	79	38	31	31	33	26
1996	1,175	878	176	255	299	149	98	48	39	39	42	33
1997	1,340	970	194	281	330	165	122	59	48	48	52	41
1998	1,531	1,072	214	311	364	182	152	74	60	60	64	51
1999	2,070	1274	255	369	433	217	263	127	103	103	111	88
2000	2,529	1,408	278	408	478	244	370	179	146	146	157	123
2001	2,926	1,556	304	450	527	275	452	219	178	178	192	151
2002	3,219	1,719	332	496	581	310	495	240	195	195	210	165
2003	3,498	1,899	362	547	641	349	528	256	208	208	224	176
2004	3,794	2,099	396	603	707	394	559	271	220	220	237	186
CAGR		1.105	1.092			1.127						CAGR
			<0.5kVA	0.5-0.9kVA	1.0 - 2.9 KVA	3.0 - 5.0 KVA	5.1-20 kVA	21-50kVA	51-100kVA	101-200kVA	201-500kVA	>500kVA
1990	Interactive Sales, Millions $US		7	102	119	60	15	-	-	-	-	-
1991	Interactive Sales, Millions $US		8	113	132	66	19	-	-	-	-	-
1992	Interactive Sales, Millions $US		9	124	146	73	23	-	-	-	-	-
1993	Interactive Sales, Millions $US		9	137	161	81	29	-	-	-	-	-
1994	Interactive Sales, Millions $US		10	152	178	89	36	-	-	-	-	-
1995	Interactive Sales, Millions $US		12	168	197	98	45	-	-	-	-	-
1996	Interactive Sales, Millions $US		13	185	217	109	56	-	-	-	-	-
1997	Interactive Sales, Millions $US		14	205	240	120	69	-	-	-	-	-
1998	Interactive Sales, Millions $US		16	226	265	133	86	0	0	0	0	0
1999	Interactive Sales, Millions $US		19	269	315	158	149	0	0	0	0	0
2000	Interactive Sales, Millions $US		20	297	348	178	210	0	0	0	0	0
2001	Interactive Sales, Millions $US		22	327	384	200	256	0	0	0	0	0
2002	Interactive Sales, Millions $US		24	361	423	226	281	0	0	0	0	0
2003	Interactive Sales, Millions $US		26	398	467	254	299	0	0	0	0	0
2004	Interactive Sales, Millions $US		29	439	514	287	317	0	0	0	0	0
1990	On-Line Sales, Millions $US		3	38	45	22	12	13	10	10	11	9
1991	On-Line Sales, Millions $US		3	42	49	25	14	16	13	13	14	11
1992	On-Line Sales, Millions $US		3	46	54	27	18	20	16	16	17	14
1993	On-Line Sales, Millions $US		4	51	60	30	22	25	20	20	22	17
1994	On-Line Sales, Millions $US		4	57	66	33	28	31	25	25	27	21
1995	On-Line Sales, Millions $US		4	63	73	37	34	38	31	31	33	26
1996	On-Line Sales, Millions $US		5	69	81	41	43	48	39	39	42	33
1997	On-Line Sales, Millions $US		5	77	90	45	53	59	48	48	52	41
1998	On-Line Sales, Millions $US		6	85	99	50	66	74	60	60	64	51
1999	On-Line Sales, Millions $US		7	100	118	59	114	127	103	103	111	88
2000	On-Line Sales, Millions $US		8	111	130	66	160	179	146	146	157	123
2001	On-Line Sales, Millions $US		8	122	143	75	196	219	178	178	192	151
2002	On-Line Sales, Millions $US		9	135	158	84	215	240	195	195	210	165
2003	On-Line Sales, Millions $US		10	149	174	95	229	256	208	208	224	176
2004	On-Line Sales, Millions $US		11	164	192	107	242	271	220	220	237	186
		TOTALS, NA	1,292	2,089	2,449	1,230	1,177	630	512	512	551	433

Figure E-2: UPS Sales, by Device Type, Power Class and Year

Appendix F: Scenario Calculation Details

Tables F-1 through F-3 list key details used to calculate the AEC projections for each equipment type and scenario. “Organic growth” denotes an increase consistent with the rate of increase of the U.S. population, i.e., 1% per year.

Table F-1: Ubiquitous Computing Forecast Scenario Summary

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Monitors-Total	22	23	15	• Increase in ENERGY STAR® enabled rate from 60% to 80%	• No growth in monitor stock
CRT	19	19	9.7	• No growth in CRT stock • 19" monitor standard	• 19" CRT monitor standard • Stock allocation 50% CRT and 50% LCD
LCD	0.04	0.05	1.5	• 20% of stock LCD	• 50% of stock
General Display	3.4	3.4	3.4	• No change from Y2000	• No change from Y2000
Display Board	0.0	0.3	0.3	• 1M LCD display boards enter market	
Computers-Total	27	34	46	• Stock growth of 5% per year •	• 5% stock growth per year from Y2005
Desktop	17	18	26	• ENERGY STAR® enabled rate increase from 25% to 50%; • More computers left on at night (“always on”)	• 50% of total stock • 50% increase in “active” power draw
Laptop	0.4	1.2	2.1	• 35% of PC stock (32M)	• 50% of total stock
Low-end server	4.5	4.5	4.5	• No stock growth	• 3% stock CAGR • 15% decrease in UEC from power management
Workhorse	3.3	5.1	6.8	• 9% CAGR	• 6% stock CAGR from Y2005
Mid-range	2.0	3.6	4.8	• 12.4% CAGR	• 6% stock CAGR from Y2005
High-end	0.4	0.4	0.5	• Organic growth	• 6% stock CAGR from Y2005
Data Storage	1.5	1.7	1.8	• 2% CAGR	• 2%CAGR
Printers-Total*	5.2	5.9	4.7	• 5% CAGR in paper consumption	• Low-end laser printer migration to

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
					dual-function copiers
Inkjet	0.6	0.6	0.7	• 10% increase in stock from Y2000	• Organic growth
Laser Printer – Small desktop	0.3	0.3	0.0	• Organic growth	• 100% of stock assimilated by low-level copiers
Laser Printer – Desktop	2.6	2.8	1.6	• Organic growth	• 45% of stock assimilated by to mid-level copiers (2.5M printers)
Laser Printer – Small Office	0.2	0.2	0.2	• Organic growth	
Laser Printer – Office	0.02	0.02	0.02	• Organic growth	
Laser Printer – Color	0.3	0.3	0.3	• Organic growth	
Copiers-Total*	9.7	10.2	10.1	• Organic stock growth • 5% CAGR in paper consumption	• Organic growth in stock • Additional increase in paper consumption due to assimilation of lower-end laser printers; 5% CAGR in paper consumption otherwise • ENERGY STAR® enabled rate increases from 34% to 50%
Band 1, Retail	0.3	0.3	0.3		
Band 1	2.1	2.2	2.3		• Assimilates 100% of Small Desktop Printer stock
Band 2	3.3	3.5	3.4		
Band 3	0.9	1.0	0.9		
Band 4	2.0	2.1	1.9		
Band 5	0.5	0.5	0.5		
Band 6	0.3	0.3	0.3		
Telephone Networks	6.1	9.6	13.9	• Doubling of cellular & PCS equipment stock	• Growth in transmission, more data/voice transfer
PBX	0.96	1.01	1.06	• Organic growth in stock	• Continued organic growth
Public Network	0.99	1.04	0.99	• Organic growth in stock	• 5% decrease in stock from 2005 • Supplanted by IP phones
Cellular & PCS	2.3	4.6	4.6	• 15% stock CAGR	• No stock growth

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	**2005**	**2010**		
Fiber terminals	1.8	2.7	6.4	• 15% stock CAGR • *New* terminals draw 50% power of older equipment (i.e., 100W)	• 3% stock CAGR from Y2005 • 300W, all terminals
IP PHONES	0.00	0.18	0.9	• 5M units come into use • 4W/unit	• 25M units • 4W/unit
Fiber to the Curb (FTTC) - Terminals	0.00	0.02	0.09	• 2M homes served, 50 homes/terminal • OC-3 Terminal; 50W/terminal	• 25M homes served, 50 homes/terminal • OC-3 Terminal; 20W/terminal
Computer Network Equipment	6.3	6.6	5.7		
LAN Switches	3.3	3.5	1.3	• Organic growth	• Saturation of LAN Switches • Power decrease to 1.5 W per port
WAN Switches	0.15	0.34	0.42	• 15% stock CAGR • In addition, DSLAMs: 3M DSL lines @ 1.25 W/line	• In addition, DSLAMs: 15M DSL lines @ 1.25 W/line
Router	1.1	1.9	3.1	• 10% stock CAGR • In addition, 2.5M DSL edge routers (businesses) @ 15W	• 10% growth from Y2000 • In addition, 5M DSL edge routers (businesses) @ 15W
Hub	1.6	0.33	0.00	• 80% decrease in stock, functionality replaced by routers	• Passive hubs essentially gone
Wireless LANS	0.00	0.21	0.58	• 12% of office workers, 10 workers/cluster. • 20 W/WLAN	• 30% of office workers, 10 workers/cluster • 20 W/WLAN
DSL	0.00	0.08	0.26	• 2.5M Subscribers • 3W/line, “always on”	• 7.5M subscribers • 3W/line, “always on”
UPSs	5.8	9.0	11.9	• 20% CAGR in 5-100kVA range (telecoms, mid-range server applications)	• 15% CAGR in 5-100kVA range (telecoms, mid-range server applications)

Note: Organic growth is defined as 5% over a five-year period.
*Energy consumption for image production is included in the total category AEC but *not* in the equipment band break downs; consequently, the category AEC is greater than the sum of the equipment band break downs.

Table F-2: Forecast Scenario Summary, PC Reigns

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Monitors-Total	22	23	23	• 75M stock • ENERGY STAR® enabled rate of 85%	• 100M stock • ENERGY STAR® enabled rate of 90%
CRT	19	20	19	• Standard is 19"	• 50% of installed monitors • 21" standard
LCD	0.04	0.6	2.3	• 15M installed • Mix of 15" and 17" screens	• 50% of installed monitors • 17" standard
General Display	3.4	2.6	1.9	• 25% decrease over 5 years	• Continued decline
Display Board	0.0	0.0	0.3		• 1M boards • 35W/board (LCD)
Computers-Total	27	48	57		
Desktop	17	33	42	• 75M installed • ENERGY STAR® enabled rate of 85% • Power draw increase to 100W (from 55W)	• Power draw peaks at 100W due to power density • 95M units
Laptop	0.4	0.7	1.1	• 10% stock CAGR	• 10% CAGR • 32M stock
Low-end server	4.5	7.2	7.9	• 10% stock CAGR	• 2% CAGR (from Y2005)
Workhorse	3.3	3.0	2.7	• (-)2% stock CAGR	• (-)2% CAGR
Mid-range	2.0	1.8	1.6	• (-)2% stock CAGR	• (-)2% CAGR
High-end	0.4	0.4	0.5	• 1.6% stock CAGR	• 3% CAGR
Data Storage	1.5	1.5	1.5	• No growth	• No Growth
Printers-Total*	5.2	6.9	5.8	• 5% CAGR paper consumption growth	• Low-end laser printer migration to dual-function copiers; organic growth otherwise • Unadjusted, 5% paper consumption CAGR from Y2005, however, actual paper consumption by printers decreases due to lower-end printer assimilation by copiers
Inkjet	0.6	0.8	0.9	• Installed base equal to that of all laser printers	• Organic growth from Y2005
Small desktop	0.3	0.4	0.0	• 5% stock CAGR	• 100% of Y2005 stock assimilated by low level copiers (Band retail, 1 and 2)

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Desktop	2.6	3.4	2.6	• 5% stock CAGR	• Stock equal to 75% of medium range assimilated into multi-function copy machines (Bands 3 and 4)
Small Office	0.2	0.2	0.26	• 5% stock CAGR	• Organic growth
Office	0.02	0.025	0.026	• 5% stock CAGR	• Organic growth
Color	0.3	0.4	0.4	• 5% stock CAGR h per year	• Organic growth
Copiers-Total*	9.7	10.2	10.1	• Same stock CAGRs and Power Draw as Ubiquitous 2005 Scenario	• Image production increase due to assimilation of lower-end laser printer functionality
Band 1, Retail	0.3	0.3	0.3		• Organic growth from PC Y2005
Band 1	2.1	2.2	2.3		• Organic growth from PC Y2005 • Assimilates all small laser copier stock
Band 2	3.3	3.5	3.4		• Organic growth from PC Y2005
Band 3	0.9	1.0	0.9		• Assimilates medium range printers
Band 4	2.0	2.1	1.9		• Assimilates medium range printers
Band 5	0.5	0.5	0.5		• Same as Ubiquitous 2010
Band 6	0.3	0.3	0.3		• Same as Ubiquitous 2010
Telecommunications Networks	6.1	9.6	12.8		
PBX	1.0	1.0	1.1	• Organic growth	• 2% Stock CAGR from Y2000 • 10% decrease in power draw / subscriber
Public Network	1.0	1.2	1.3	• 4% line CAGR	• 4% line CAGR • 10% decrease in power draw / line
Cellular & PCS	2.3	3.7	4.8	• 10% stock CAGR	• 5% CAGR in cell stations Y2005
Fiber terminals	1.8	3.6	5.5	• 35% increase in stock (4x bandwidth increase, 40% in data transfer CAGR) • 50% increase in power draw per terminal (Upgrade to OC-192)	• Same terminal stock as Y2005 • 50% increase in power draw per terminal (i.e., 300W, higher bandwidth)

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Fiber to the Curb – Terminals (FTTC)	0.0	0.00	0.20		• 7.5M installed base at 3W/line
Computer Networks	6.3	6.8	7.0		
LAN Switches	3.3	3.9	1.6	• 17% total growth (same as PCs)	• 2% stock CAGR from Y2005 • Power decrease to 1.5W per port
WAN Switches	0.2	0.3	0.6	• 10% stock CAGR • In addition, includes DSLAMs, 4.5M DSL lines @ 1.25W	• 10% stock CAGR from Y2005 • In addition, includes DSLAMs, 15M DSL lines @ 1.25W
Router	1.1	2.4	3.9	• 15% stock CAGR • In addition, 1M DSL edge routers at 15W (businesses)	• 5% stock CAGR from Y2005 • 25% increase in power draw (high bandwidth demand) • In addition, 2M DSL edge routers at 15W (businesses)
DSL	0.0	0.12	0.5	• 4.5M lines • 3W/line ; “always on”	• 20M lines • 3W/line; “always on”
Wireless LANS	0.0	0.09	0.3	• 5% of office workers, 10 workers/cluster. • 20W/WLAN	• 15% of office workers, 10 workers/cluster • 20W/WLAN
UPSs	5.8	12.4	18.9	• 20% stock CAGR in 20kVA+ range • 25% of PCs with Stand-by UPS	• 10% stock CAGR in 20kVA+ range • 50% of PCs with Stand-by UPS

Note: Organic growth is defined as 5% over a five-year period.

*Energy consumption for image production is included in the total category AEC but *not* in the equipment band break downs; consequently, the category AEC is greater than the sum of the equipment band break downs.

Table F-3: Forecast Scenario Summary, Greening of IT

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Monitors-Total	22.2	18.7	7.4	• 75% of PC stock • ENERGY STAR® enabled rate of 90%	• 2/3 of the PC stock (~74M) • ENERGY STAR® enabled rate of 95%
CRT	18.7	14.5	2.3	• ~52M units installed • 17" standard size	• 20% of stock • 19" standard
LCD	0.04	0.4	1.4	• ~13M units installed • 15" standard size	• 80% of stock • 17" standard
General Display	3.4	3.4	3.4		
Display Board	0.0	0.3	0.3	• 1M LCD display boards enter market	
Computers-Total	28	28	25	• Same as Ubiquitous Y2005 stock	• Same as Ubiquitous Y2010 stock
Desktop	17.4	14.6	8.5	• 75% of the stock • ENERGY STAR® enabled rate of 75%	• 1/3rd of PC stock • ENERGY STAR® enabled rate of 95%
Laptop	0.4	0.8	1.4	• 25% of total stock • Approximately doubling of stock	• 1/3rd PC stock
Power-Aware Desktop	0.0	2.6	4.4	• Power draw 30W active • 25% of PC stock	• 1/3rd PC stock • 30W "active" power draw • 100% ENERGY STAR®
Low-end server	4.5	2.5	2.7	• 2% stock CAGR • 50% reduction in UEC (from Y2000	• 2% stock CAGR • Same UEC as Y2005
Workhorse	3.3	3.6	3.7	• 4% stock CAGR • 10% decrease in UEC	• 3% stock CAGR from Y2005 • 20% decrease in UEC (from Y2000)
Mid-range	2.0	2.6	2.6	• 7% stock CAGR • 10% decrease in UEC	• 3% stock CAGR from Y2005 • 20% decrease in UEC (from Y2000)
High-end	0.4	0.5	0.6	• 6% stock CAGR • Supplants some low-end servers • No change in UEC	• 5% stock CAGR from IT Y2005 • 90% of Y2000 power draw
Data Storage	1.5	1.3	1.1	• (-)3% AEC CAGR	• (-)3% AEC CAGR

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Printers-Total*	5.2	6.1	4.3	• 2.5% paper CAGR • 25% reduction in low power time, increase in off time	• 2.5% paper CAGR and additional decrease in image production due to printer migration to copiers
Inkjet	0.6	0.5	0.5	• 9% stock CAGR • In addition, assimilates 25% of the low-end laser printer stock • Increase from 24% to 50% night Off	• Organic growth from Y2005 • In addition, assimilates 50% of the stock of small desktop laser printers
Small desktop	0.3	0.4	0.2	• 5% stock CAGR • 25% of stock (after 5% CAGR) assimilated by inkjet printer category	• No growth • 50% of stock re-allocated to inkjets
Desktop	2.6	3.3	1.9	• 5% CAGR	• 25% reduction in stock from IT Y2005 • 1/3 of medium copier stock assimilated by copiers
Small Office	0.2	0.23	0.2	• 5% stock CAGR	• 25% reduction in stock from IT Y2005
Office	0.02	0.02	0.02	• 5% stock CAGR	• 25% reduction in stock • 16% assimilated by band 3&4 copiers
Color	0.3	0.36	0.3	• 5% stock CAGR	• 25% reduction in stock
Copiers-Total*	9.7	7.6	5.1	• 5% stock CAGR paper growth • 70% ENERGY STAR® enabled rate • 70% night off rate • 15% decrease in power, all modes	• 5% stock reduction for all bands from Y2005 • 5% reduction in paper use from Y2005, but an increase in image production due to assimilation of desktop printers • 90% ENERGY STAR® enabled rate • 90% Night off rate • 30% decrease in power (from Y2000), all modes
Band 1, Retail	0.3	0.2	0.1	• 2% stock CAGR	
Band 1	2.1	1.3	0.8	• 1% stock CAGR	
Band 2	3.3	2.4	1.5	• 2% stock CAGR	
Band 3	0.9	1.1	0.7	• 11% stock CAGR	
Band 4	2.0	1.8	1.2	• 5% stock CAGR	
Band 5	0.5	0.3	0.2	• (-)1% stock CAGR	
Band 6	0.3	0.2	0.1	• (-)1% stock CAGR	

Equipment	AEC, TW-h			Key Assumptions, 2005	Key Assumptions, 2010
	Y2000	2005	2010		
Telephone Networks	6.1	9.2	9.7		
PBX	1.0	1.0	1.3	• Organic growth	• 3% CAGR from Y2005 (2nd line growth)
Public Network	1.0	1.0	0.9	• Organic growth	• Organic growth • 15% reduction in UEC
Cellular & PCS	2.3	4.2	4.2	• 13% stock CAGR • Same Power Draw	• 15% stock growth from Y2005 • 15% decrease in power draw
Fiber terminals	1.8	2.9	3.4	• 10% stock CAGR	• 5% CAGR from Y2005 • 180W each
Computer Networks	6.3	5.34	5.13		
LAN Switches	3.3	2.61	1.38	• 20% reduction in unit power draw/port • Organic growth	• Organic growth • 1.5W/port
WAN Switches	0.2	0.28	0.36	• No traditional WAN growth • In addition, DSLAMs: 3.5M lines, 1.25W/line	• No traditional WAN growth • In addition, DSLAMs: 13M lines, 1W/line
Router	1.1	1.94	2.61	• 10% stock CAGR • 20% reduction in UEC • In addition, 750,000 DSL edge routers (businesses) at 15W each	• 5% CAGR • 40 W each • In addition, 1.5 MDSL edge routers (businesses) at 15 W each
Hub	1.6	0.41	0.00	• 75% stock reduction from Y2000	Passive hubs phased out
Wireless LANS	0.0	0.00	0.26		• 1.5M • 20 W each
DSL	0.0	0.09	0.53	• 3.5M lines • 3W/line	• 13M lines • 3W/line
UPSs	5.8	7.8	9.1	• 10% stock CAGR • 15% decrease in online system power dissipation	• 10% stock CAGR • 43% decrease in online system power dissipation

Note: Organic growth is defined as 5% over a five-year period.
*Energy consumption for image production is included in the total category AEC but *not* in the equipment band break downs; consequently, the category AEC is greater than the sum of the equipment band break downs.

Appendix G: Usage Calculation Details for Office Equipment

Table G-1: Weekly Hours Breakdown by Equipment Type

Equipment	Night/Weekend Hours	Weekday Hours	Sources
PC – Desktop	120	48	Kawamoto et al. (2001)
PC – Laptop	120	48	Kawamoto et al. (2001)
Monitor and General Display	120	48	Kawamoto et al. (2001)
Copy Machine	107	61	Kawamoto et al. (2001)
Impact Printer	112	56	ADL Estimate
Inkjet Printer	128	40	ADL Estimate
Laser Printer	112	56	Kawamoto et al. (2001)

Table G-2: Power Management (PM) Enabled Rates by Equipment Type

Equipment	PM	Non-PM	Sources
PC – Desktop	.25	.75	Nordman et al. (2000)
PC – Laptop	1	0	Kawamoto et al. (2001)
Monitor and General Display	0.6	0.4	Nordman et al. (2000)
Copy Machine	.34	.66	Kawamoto et al. (2001), Nordman et al. (1998)[201]
Impact Printer	0	1	ADL Estimate
Inkjet Printer	1	0	ADL Estimate
Laser Printer	.54	.46	ADL Estimate, Webber et al. (2001)[202]

[201] Kawamoto et al. (2001) applied a 34% "sleep" PM rate, and an additional 34% "sleep-auto off" PM rate. In light of Nordman et al. (1998), which noted that about 1/3rd of all copiers were Energy Star compliant, and 2/3rd of those compliant copiers are enabled, the Kawamoto et al. (2001) rate seemed high. Instead, the 34% "sleep" PM rate reflects that during the day most copiers would not have much opportunity (i.e., sufficient time between copies) to enter "auto off" mode. In the structure of the current usage model for copiers, the PM rate assumption in Table F-2 has *no* impact upon energy consumption, since no copiers are assumed to enter "sleep" mode during the day and the night status data are independent of the PM rate in Table F-2.

[202] Night audits by Webber et al. (2001) of 338 monochrome laser printers found that 35% and 41% of printers were in "on" and "low power" modes, respectively. This suggests a PM-enabled rate of 54% (=41%/76%).

Table G-3: Daytime Equipment Status by Mode

Equipment		Fraction of Time in Position			Sources
		On	Low	Off	
PC – Desktop	PM	.4	.4	.2	Kawamoto et al. (2001)
	No PM	.8	0	.2	
PC – Laptop	PM	.4	.4	.2	Kawamoto et al. (2001)
	No PM	.8	0	.2	
Monitor and General Display	PM	.4	.4	.2	Kawamoto et al. (2001)
	No PM	.8	.0	.2	
Copy Machine	PM	.9	0	.1	ADL Estimate[203], Kawamoto et al. (2001)
	No PM	.9	0	.1	
Impact Printer	PM	.135	.765	.1	Sturcke (2001), Kawamoto et al. (2001)
Inkjet Printer	PM	.03	.77	.02	Meyer and Schaltegger (1999)
Laser Printer[204]	PM	.45	.45	.1	Kawamoto et al. (2001)
	No PM	.9	.0	.1	

[203] Kawamoto et al. (2001) assumed that "on" copiers spend 50% of daytime hours in sleep mode; we modified this assumption to reflect copier usage in an office setting, but kept their assumption that 10% of copiers are "off" during the day.

[204] Unfortunately, we could not locate laser printer usage mode data segregated by printer class; for instance, low-speed printers very likely spend many more weekday hours in "low" power mode than high-speed printers.

Table G-4: Nighttime Equipment Status by Mode

Equipment	Fraction of Time in Position			Sources
	On	Low	Off	
PC – Desktop	.54	.02	.44	Webber et al. (2001)
PC – Laptop	.00	.56	.44	Webber et al. (2001)
Monitor and General Display	.30	.38	.32	Webber et al. (2001)
Copy Machine	.29	.38	.33	Nordman et al. (1998)
Impact Printer	0	.69	.31	Webber et al. (2001)
Inkjet Printer	0	.69[205]	.31	Webber et al. (2001)
Laser Printer	.41	.35	.24	Webber et al. (2001)

Table G-5: Average Weekly and Annual Usage Time by Mode

Equipment		Time in Position		
		On	Low	Off
PC – Desktop	Hours/Week	98.4	7.2	62.4
	Hours/Year	5,131	375	3,254
PC – Laptop	Hours/Week	19.2	86.4	31.2
	Hours/Year	1,001	4,505	3,254[206]
Monitor and General Display	Hours/Week	62.9	57.1	48.0
	Hours/Year	3,281	2,980	2,505
Copy Machine	Hours/Week	85.9	40.7	41.4
	Hours/Year	4,481	2,120	2,159
Impact Printer	Hours/Week	7.6	120.1	40.3
	Hours/Year	394	6,263	2,102
Inkjet Printer	Hours/Week	1.15	119.2	47.68
	Hours/Year	60	6,215	2,486
Laser Printer	Hours/Week	76.0	59.5	32.5
	Hours/Year	3,962	3,104	1,694

[205] Includes inkjet printers in both "low power" and "on" modes used by Webber et al. (2001).

[206] Reflects an assumption of 1,627 hours off and plugged in and 1,627 hours off and unplugged.

Appendix H: Internet Appliance AEC Calculations

Ma et al. (2001) broke down Internet appliances into several categories and presented installed base estimates for each (see Table H-1).

Table H-1: Internet Appliance Installed Base, from Ma et al. (2001)

Equipment Type	Installed Base (thousands)	Comments / Representative Device
Web Terminals	148	3com Audrey[207]
Web Tablets	1	Did not calculate – small stock
Email Terminals	187	Landel Mailbug[208]
Internet Handheld Vertical Application Devices	571	Fujitsu Stylistic 3500[209]
Thin Enterprise Clients	2,064	Wyse Winterm 3720SE[210]
Home Audio Clients	1	Did not calculate AEC – small stock
iTV-enabled Devices	6,627	Digital Set-top Box (e.g., Scientific-Atlanta)
Internet Gaming Devices	4,528	Primary function is gaming – inclusion debatable; Sony Play Station 2
Other	199	Did not calculate AEC

In general, the internet appliance AEC calculations are very rough and intended to provide only a general estimate for internet appliance energy consumption. To develop an upper bound, many of the AEC calculations apply very conservative assumptions in combination with information found in product data sheets and descriptions, as well as prior studies of similar equipment (see Table H-2). In additional the AEC estimate attributes all of the energy consumed by the devices to the Internet, a point of debate for iTV-enabled and internet gaming devices.

[207] Information available at: http://www.3com.com/products/en_US/detail.jsp?tab=support&pathtype=support&sku=3C8300AUBLK-01 .

[208] Information available at: http://www.mailbug.com/index.html .

[209] Information available at: http://www.fpc.fujitsu.com/www/products_pentablets.shtml?products/pentablets/stylistic_3500 .

[210] Information available at: http://www.wisesystems.co.uk/buys/pdf/3720[1].pdf .

Table H-2: Internet Appliance Upper Bound AEC Estimate

Device Type	UEC (kW-h)	AEC (TW-h)	Comments and Sources
Web Terminals	88	0.013	Estimated 10W power draw; assumed "active" 8,760 hours a year (very aggressive)
Email Terminals	88	0.016	Estimated 10W power draw; assumed "active" 8,760 hours a year (very aggressive)
Internet Handheld Vertical Application Devices	32	0.018	Designed to run off of battery (3.1W-h Li-ion), uses 1.1V ultra-low power processor; assumed same UEC as laptop (very aggressive)
Thin Enterprise Clients	32	0.40	Wyse Winterm has a 15-inch CRT monitor, with low-power processor and automatic power management. Assumptions: usage = laptop; power = laptop + 15-inch CRT.
iTV-enabled Devices	200	1.3	Assumed same UEC as digital set-top box (Rosen et al., 2001); actual UEC may be somewhat higher
Internet Gaming Devices	20	0.09	Doubled UEC estimate of Rosen et al. (2001) to reflect likely higher power draw of newer devices
Upper Bound Internet Appliance AEC		1.9	

Altogether, internet appliances contribute at most 1.9 TW-h of electricity to the total "Internet" AEC, or about 2% of the upper-bound estimate. Ma et al. (2001) expect the installed base of internet appliances to grow dramatically over the Y2000 to Y2005 time period.